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CONTENTS

ERRATUM

Gill, Robert, Jr. 1979. Status and distribution of the California Clapper Rail. California Fish and Game, 65(1): 36–49.

Page 47. First sentence of second paragraph should read:

"Mahall and Park (1976*b*), during a study of plant zonation in salt marshes in San Pablo Bay in 1972–1973, found *Spartina* to be much less tolerant than *Salicornia* to quick changes in salinity, and that higher salinities inhibited the growth of *Spartina*."

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THE DIET COMPOSITION AND ENERGY RESERVES OF CALIFORNIA MULE DEER DURING PREGNANCY [1]

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Data were obtained on the growth, diet composition, and energy reserves of 102 California mule deer (*Odocoileus hemionus californicus*) does collected from the North Kings deer herd from January through June, 1971 through 1975. Growth parameters indicated that the growth rates and age-specific sizes were normal or above normal for this subspecies of migratory deer. The composition of the does' diet fluctuated in response to plant phenology and elevation. A diet dominated by mature browse during the spring migration led to a decline in the energy reserves of the does during the last trimester of gestation. The depletion of energy reserves may have had an adverse effect on fetal metabolism or the lactation capabilities of the does and may have been an important factor resulting in the high neonatal mortality observed in this herd.

INTRODUCTION

California mule deer herds migrate along the west slope of the Sierra Nevada. During the past 25 years, most of these migratory herds have declined significantly. The North Kings deer herd is considered representative of many of these herds. Since the mid-1950's, declining fawn survival has resulted in an approximate 70% decline in this herd's population. Owing to its convenient geographical location and the progressive attitudes of local sportsmen, the North Kings deer herd was selected for a 10-year study. The purposes of this study were to identify those factors responsible for the population decline and to evaluate the effects of various management practices on a migratory deer herd (Winter, Ashcraft, and Stewart 1970; Salwasser, Holl, and Ashcraft 1978).

Cowan and Wood (1955) stated that the animal itself was the most satisfactory measure of the adequacy of its range. Previous studies have used growth rates and age-specific size as indicators of a cervid's range quality (Taber and Dasmann 1958; Julander, Robinette, and Jones 1961; Klein, 1964, 1968; Reimers 1972; and Dauphiné 1976). Limitations of forage quality, particularly on the spring and summer ranges, inhibit growth rates and the ultimate body size of deer (Klein 1970).

In a review of the recent history of California's deer herds, Longhurst, Garton, Heady, and Connolly (1976) considered inadequate nutrition to be an important factor responsible for the decline of many of the State's deer herds. Salwasser et al. (1978) hypothesized that the deterioration of habitat quality due to plant

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succession, resulting in a lowered maternal nutritional plane during late gestation, has been an important ecological factor determining fawn survival in the North Kings deer herd.

Two objectives of the North Kings deer herd study were to determine age-specific sizes of does and to determine diet composition and energy reserves of does during pregnancy, particularly during the last one third of gestation, when maternal energy requirements are high (Moen 1973).

The Study Area

The North Kings deer herd is located 48 km (30 miles) northeast of Fresno, California. Its range encompasses approximately 2,100 km ^{2} (800 square miles), of which 90% is public land.

The herd is on the winter range, at 360–1,100 m (1,200–3,600 ft) elevation, from the middle of November to late April. The vegetation is characteristic of the foothill woodland and chaparral communities of California (Munz and Keck 1959).

The herd occupies its summer range from late May to early November, at 1,800–3,000 m (6,000–10,000 ft) elevation. Yellow pine and mixed conifer communities characterize the lower elevations. Red fir, lodgepole pine, and subalpine communities characterize the higher elevations (Munz and Keck 1959).

METHODS AND MATERIALS

Does were shot by personnel from the California Department of Fish and Game from late January through late June, 1971 through 1975. Occasionally, we obtained does that had died in highway accidents and during trapping sessions in concurrent studies of this herd. The timing and location of each collection period was determined by weekly monitoring the movements of radio-collared does in the herd (Bertram and Rempel 1977).

To facilitate the interpretation and analyses of data, the 15 January to 30 June time span was partitioned into five biological collection periods (Table 1). Periods were partitioned on the basis of available data on local plant phenology (Chesemore 1975, Chesemore, et al. 1976), movement patterns of this herd (Bertram and Rempel 1977), and physiologic considerations (Moen 1973).

Collected animals were transported to a field camp where necropsies were performed. Each animal was weighed to the nearest kilogram on a spring scale to obtain the bled carcass weight. Measurements of the right hindfoot length (proximal tip of the calcaneum to the distal tip of the hoof), contour length (distal tip of the nose dorsally to the base of the tail), and chest girth (circumference of the chest, just posterior to the edge of the scapulae) were recorded to the nearest centimeter with a flexible steel tape.

Body fat index (Bischoff 1954), as measured by internal fat deposits, was used as an index of the does' adipose tissue reserves. For this index the abundance of fat present on the ribs, brisket, rump, kidneys, omentum mesentery, and heart were each rated subjectively as none, light, moderate, or heavy; ratings were assigned zero, one, two, or three points, respectively. The body fat index is the sum of the six ratings. Therefore, as an index of adipose tissue reserves, 18 would be considered excellent, 12 good, and below 6, poor. Kidney fat index (Riney 1955) was also recorded, but this will be reported in a separate paper.

TABLE 1. Description of the Five Biological Collection Periods, 1971 Through 1975, for the North Kings Deer Herd.

Time	*Name*	*Description*
15 January–21 March....	Winter	Deer are on the winter range; elevation 360–1,100 m. Includes first half of second trimester of gestation. Early emerging shrubs showing limited growth, new growth of forbs evident, many grasses showing vigorous growth.
22 March–15 April	Winter range green-up	Deer are on the winter range. Last half of the second trimester of gestation. Shrubs showing varied phenology; forbs and grasses with inflorescences or fruits.
16 April–20 May...........	Early spring migration	Deer begin to test the migration corridors; elevation 850–1,500 m. Initiates the third trimester of gestation. Most shrubs have broken their buds and are initiating new leader growth. Most forbs and grasses have mature fruit or are drying.
21 May–5 June	Late spring migration	Deer are on upper portions of the migration corridors and lower summer range; elevation 1,500–1,900 m. Initiates second half of third trimester of gestation. Shrubs showing varied phenology; few have initiated leader growth.
6 June–30 June	Summer range green-up	Most deer are established on summer home ranges; elevation 1,800–3,000 m. One to 3 weeks pre-parturition. Shrubs initiating vigorous leader growth. Most forbs and grasses initiating growth and inflorescence.

For each doe, the rumen-reticulum was removed and weighed. A sample of the contents was preserved in 10% formalin for subsequent analyses by California Department of Fish and Game personnel. Diet composition was determined by percentage volume; plant species names follow those of Munz and Keck (1959). Remaining rumen-reticulum contents were discarded. Each rumen-reticulum was washed and its empty weight recorded.

Beginning in 1973, uteri and their contents were removed and weighed. This weight, subtracted from the bled carcass weight, yielded the modified bled carcass weight. This procedure allowed for a better estimate of growth, as it eliminated the weight increments associated with pregnancy.

Following the removal of all entrails, the carcass was again weighed to obtain the eviscerated carcass weight.

For does with deciduous dentition, ages were estimated on the basis of tooth replacement (Robinette, Jones, Rogers, and Gashwiler 1957). For does with permanent dentition, ages were assigned based on counts of cementum annuli in the first incisor. Age classes of does included yearlings (12–23 months), 2-year-olds (24–35 months), 3-year-olds (36–47 months), and 4-year-old-plus (48+months).

RESULTS

During the 5-year study, 102 does were collected from the North Kings deer herd. In the winter collection period a small sample size ($n = 9$) resulted in an uneven age class distribution, favoring 4-year-old-plus does (Figure 1). Larger sample sizes in the succeeding collection periods resulted in relatively homogeneous age class distributions.

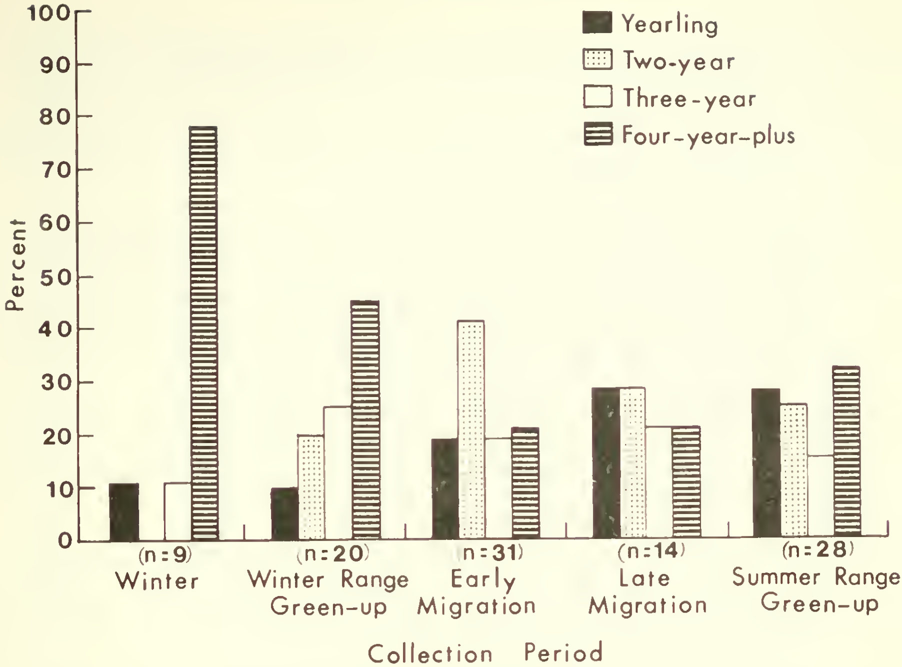

FIGURE 1. Relative percent of age classes collected during each biological period for the North Kings deer herd, 1971 to 1975. Sample sizes in parentheses.

Growth

Age-specific size provides an indication of the average nutritional plane of an animal over a longer period of time than that indicated by depot fat reserves (Caughley 1972). In general, analyses of selected parameters of growth indicated that yearlings were significantly smaller than does greater than 3 years of age (Table 2). Comparisons of differences between age classes of does were performed with one-tailed, Mann-Whitney tests (Sokal and Rohlf 1969).

TABLE 2. Descriptive Statistics ($\bar{x} \pm$ S. D.) and Analyses* of Selected Parameters of Growth for All Does Collected from the North Kings Deer Herd, January to June, 1971 through 1975. Sample sizes are in parentheses. Within each column, values with the same subscripts are significantly different ($\alpha = 0.05$)

Age (years)	*Right hindfoot length (cm)*	*Contour length (cm)*	*Eviscerated carcass weight (kg)*	*Modified bled carcass weight (kg)*	*Bled carcass weight (kg)*
1	44.1 ± 1.4 (15)	127.0 ± 6.4 (15) $_{a,b}$	32.4 ± 3.3 (20) $_{a,b}$	41.6 ± 3.2 (13) $_{a,b}$	45.3 ± 6.3 (21) $_{a,b}$
2	44.0 ± 1.1 (20)	130.6 ± 6.7 (20) $_{c}$	33.7 ± 3.2 (27) $_{c}$	42.4 ± 3.9 (20) $_{c,d}$	48.5 ± 5.9 (28) $_{a}$
3	43.8 ± 1.4 (14)	133.1 ± 6.2 (14) $_{b}$	34.8 ± 2.6 (17) $_{a}$	44.9 ± 3.9 (12) $_{a,c}$	49.4 ± 4.8 (17) $_{b}$
4+	44.0 ± 1.2 (16)	132.3 ± 5.8 (16) $_{a}$	35.7 ± 3.8 (33) $_{b,c}$	47.6 ± 4.5 (14) $_{b,d}$	51.9 ± 6.7 (33) $_{a}$

* Mann-Whitney, one-tailed test.

The hindfoot length of yearling does was similar to that of the 4-year-old-plus does, indicating that adult length of the hindfoot was reached prior to a doe's second birthday.

Contour length, the most variable parameter measured, grew at a slower rate than the hindfoot length. There were no significant differences ($P > 0.05$) between successive age classes. The contour length of the yearlings was, however, significantly smaller ($P < 0.05$) than that of 3-year-old and 4-year-old-plus does. Contour lengths probably reached adult proportions prior to a doe's third birthday.

Body weight is known to fluctuate seasonally in mule deer (Leopold et al. 1951; Wood, Cowan, and Nordan 1962; Bandy, Cowan, and Wood 1970; Anderson, Medin, and Bowden 1972, 1974). Females are generally heaviest during the rut and lightest during the spring. Eighty-five percent of the does in this study were collected during the spring (22 March to 21 June). Therefore, we feel that the weights observed probably represent the annual minima for does in this herd.

Yearling does had significantly smaller ($P < 0.05$) eviscerated carcass weights, modified bled carcass weights, and bled carcass weights than 3-year-old and 4-year-old-plus does. The bled carcass weight of yearling does was also significantly smaller ($P < 0.05$) than that of 2-year-old does.

Two-year-old does had significantly smaller ($P < 0.05$) eviscerated carcass weights, modified bled carcass weights, and bled carcass weights than 4-year-old-plus does. The modified bled carcass weight of 2-year-olds was also significantly smaller ($P < 0.05$) than that of 3-year-old-does.

Diet Composition

During the winter period (15 January to 21 March), grasses and sedges comprised approximately 44% of the diet of does collected from the North Kings deer herd (Figure 2). Forbs, primarily *Brodiaea* spp; filaree, *Erodium botrys* and *E. circutarium;* and popcorn flower, *Plagiobothrys* spp, made up 37% of the diet (Table 3). Browse, primarily interior live oak, *Quercus wislizenii,* and Mariposa manzanita, *Arctostaphylos mariposa,* comprised approximately 18% of the does' diet.

In the next period, the winter range green-up period, (22 March to 15 April), grasses, sedges, and forbs continued to dominate the does' diet. Browse, primarily interior live oak, made up only 7.7% of the diet.

In the early spring migration period (16 April to 20 May), does began to move off the winter range and test their migration corridors. The quantity of grasses and sedges in the diet declined by approximately 30%. The use of forbs during this period, primarily clover, *Trifolium spp,* and bird's foot trefoil, *Lotus spp,* declined to approximately 35% of the diet. Browse, primarily interior live oak, poison oak, *Rhus diversiloba,* and buckbrush, *Ceanothus cuneatus,* increased to 52% of the diet. Mean rumen-reticulum fill increased from 2.2 to 2.5 kg (4.8 to 5.5 lb) (Figure 2).

During the late spring migration period (21 May to 5 June), as the does began arriving on their summer home ranges, the quantity of browse, primarily mountain whitethorn, *Ceanothus cordulatus,* gooseberry, *Ribes* spp, and white fir, *Abies concolor,* increased to 85% of the diet (Table 4). Forbs made up 12% of their diet. Mean rumen-reticulum fill increased slightly to 2.6 kg (5.7 lb).

During the last period, the summer range green-up, (6 June to 30 June), the use of grasses and sedges and of forbs increased as they became available, to 10 and 24%, respectively. Lichens and fungi comprised approximately 3% of the diet. Mean rumen-reticulum fill declined to 2.3 kg (5.1 lb).

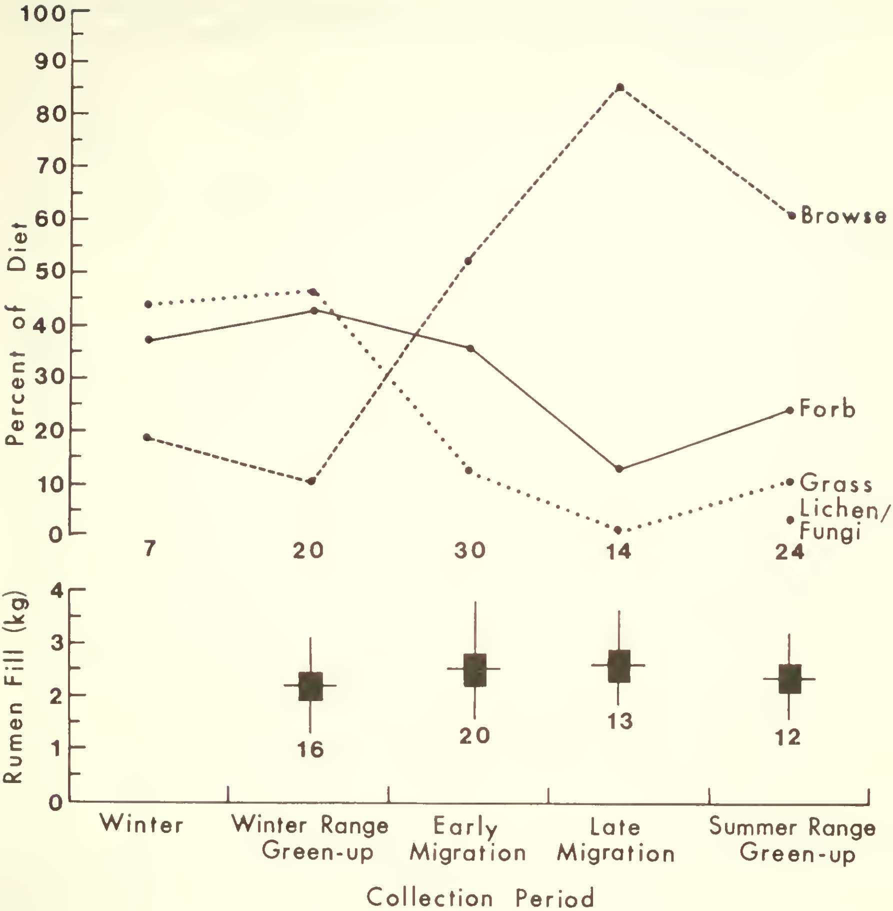

FIGURE 2. Percent diet composition and mean (horizontal line), 95% confidence intervals (rectangle), and range (vertical line), of the weight of rumen-reticulum contents of does collected from the North Kings deer herd for each biological period, 1971 to 1975. Sample sizes given below each statistic.

Energy Reserves

The body fat indices of yearlings were treated separately because yearlings devote most of their energy toward the accumulation of body mass and because yearlings have lower fecundity (Figure 3). Statistical analyses were performed with two-tailed, Mann-Whitney tests. No statistical analyses were performed on the yearling age class because of small sample sizes. The trends, however, approximate those of the 2-year-old-plus animals.

During the winter period, the body fat indices of the 2-year-old-plus does (7.6 $\pm$ 2.9) indicated that they were approaching a poor physical state. During the winter range green-up period, when forage availability and quality were high, the body fat indices of the 2-year-old-plus does increased to 12.4 $\pm$ 3.7. This change in energy reserve indices of the does from the winter to the winter range green-up period was significant ($P < 0.05$).

TABLE 3. Forage Items Comprising More Than One Percent of the Diet for All Does Collected During the Winter, Winter Range Green-up, and Early Migration Periods, 1971 through 1975

Forage items	Winter (n = 7) Volume (%)	Winter (n = 7) Frequency	Winter range green-up (n = 20) Volume (%)	Winter range green-up (n = 20) Frequency	Early migration (n = 30) Volume (%)	Early migration (n = 30) Frequency
Grasses and sedges	44.3	7	46.7	20	11.7	30
Forbs						
Brodiaea spp	12.2	4	2.4	12	2.1	8
Clematis spp	–	–	–	–	1.5	2
Erodium botrys	3.4	5	15.9	6	1.3	5
E. circutarium	7.3	1	14.3	13	1.4	8
Lotus spp	5.0	2	T	7	3.2	11
Montia perfoliata	T	1	1.5	7	1.4	17
Plagiobothrys spp	6.4	1	T	4	–	–
Potentilla spp	–	–	–	–	1.2	2
Trifolium spp	T	3	4.6	8	8.2	13
Unidentified	2.3	3	4.5	4	13.7	21
Subtotal, forbs	36.6		43.2		34.0	
Browse						
Aesculus californica	1.6	3	T	4	2.4	7
Arctostaphylos mariposa	7.7	3	T	1	3.3	7
Ceanothus cuneatus	T	3	T	11	5.9	17
C. integerrimus	–	–	–	–	3.8	5
Cercocarpos betuloides	T	1	T	8	3.0	14
Chamaebatia foliosa	–	–	–	–	3.4	7
Lonicera interrupta	–	–	T	4	2.9	3
Quercus wislizenii	8.0	3	6.2	9	14.8	11
Rhamnus crocea	–	–	T	7	2.0	13
Rhus diversiloba	–	–	–	–	6.2	8
Salix spp	–	–	–	–	1.8	1
Symphoricarpos spp	T	2	1.5	2	T	5
Subtotal, browse	17.3		7.7		49.5	
Total	98.2		97.6		95.2	

T = trace amount

In the following period, the early spring migration, the body fat indices of the 2-year-old-plus does decreased to 10.4 ± 3.8. The energy reserves of these does continued to decrease, to 7.6 ± 3.9, through the late migration period when they were reaching their summer ranges. This change in the energy reserve indices of the does from the winter range green-up period, when does were at peak condition, to the late spring migration period was significant ($P < 0.05$).

During the summer range green-up, the body fat indices of the 2-year-old-plus does increased to 10.5 ± 4.1 as forbs, grasses, and sedges became available.

DISCUSSION

Anderson et al. (1974) found that the hindfoot length of Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) does reached adult length by approximately 36 months of age. Leopold et al. (1951) showed that the hindfoot length of does from the Jawbone deer herd, 48 km (30 miles) north of the North Kings herd, continued to grow beyond 2 years of age. In our study, the hindfoot

TABLE 4. Forage Items Comprising More Than One Percent of the Diet for All Does Collected During the Late Migration and Summer Range Green-up Periods, 1971 Through 1975

	Period			
	Late migration (n = 14)		Summer range green-up (n = 24)	
Forage items	*Volume (%)*	*Frequency*	*Volume (%)*	*Frequency*
Grasses and sedges	1.0	12	10.9	17
Forbs				
Colinsia spp	–	–	1.9	1
Gayophytum spp	T	3	4.0	13
Phacelia spp	6.4	2	T	1
Unidentified	5.8	12	17.6	20
Subtotal, forbs	12.2		23.5	
Browse				
Abies concolor	11.1	8	1.5	8
Arctostaphylos patula	9.0	5	1.5	10
Ceanothus cordulatus	28.3	13	44.2	20
C. parvifolius	5.3	3	–	–
Chamaebatia foliosa	2.8	2	T	2
Prunus emarginata	5.8	1	4.3	5
Ribes spp	14.8	11	8.0	13
Symphoricarpos spp	7.8	3	T	1
Subtotal, browse	84.9		59.5	
Lichens/Fungi	T	10	3.1	18
Total	98.1		97.0	

T = trace amount

length of the does appears to reach adult length before their second birthday. The hindfoot lengths of all age classes of does from the North Kings deer herd were also larger than those reported for the Jawbone deer herd (Leopold et al. 1951).

Anderson et al. (1974) indicated that the contour length of does from Colorado grew significantly beyond 37 months of age; however, the majority of growth was probably completed by 48 months of age. The growth regime of the contour length of does from the North Kings deer herd was completed prior to their third birthday. Thus, the nutritional quality of the summer range is adequate for the early maturation of bone development for the does of this herd.

The eviscerated carcass weights for all age classes and the bled carcass weights of does less than 4 years old were larger than those reported for does collected during a similar period from the Railroad Flat deer herd 136 km (85 miles) north of the North Kings deer herd (Browning, Schulenburg, and Brunetti 1973). Does in the North Kings deer herd probably reach their asymptotic weight in their fourth year, which is similar to that for four races of black-tailed deer (Bandy et al. 1970).

The significant difference between the bled carcass weights of yearling and 2-year-old does was apparently related to age-specific fecundity patterns rather than to the growth rates or physical condition of the does. Salwasser et al. (1978) showed that fecundity of yearlings in this herd was the lowest of all age classes.

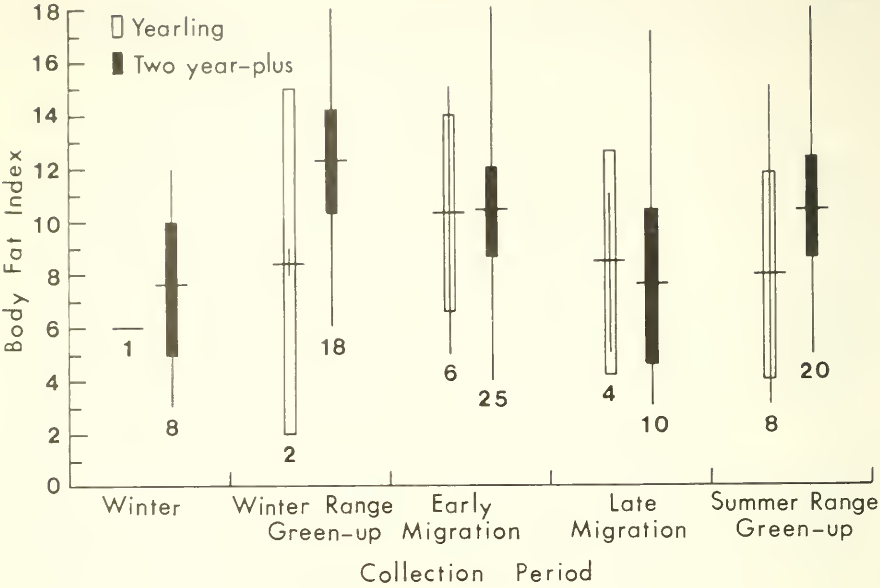

FIGURE 3. Mean (horizontal line), 95% confidence intervals (rectangle), and range (vertical line), for the body fat indices of yearling and two-year-old-plus does collected from the North Kings deer herd, 1971 to 1975, for each biological period. Sample sizes given below each statistic.

Modified bled carcass weights of yearlings and 2-year-old does were not significantly different. Therefore, the bled carcass weight is an inaccurate measure of growth when comparing age classes having different reproductive potentials; instead, the modified bled carcass weight should be used.

The physical condition of deer is largely the result of diet. During the winter period, the physical condition of the does, as measured by depot fat reserves, was approaching a poor state as they depleted the energy reserves acquired over the previous summer and fall. Trout and Thiessen (1968) have termed the period from January to April as one of deconditioning for mule deer on a diet of browse and grass in Idaho.

During the winter range green-up period, the does' diet was dominated by non-browse species of forage. The high use of grasses, sedges, and forbs during some period of an annual cycle has been well documented for mule deer (Dixon 1934, Trout and Thiessen 1968, Klein 1970, Browning et al. 1973, and Short (1975). On one study site on the North Kings winter range, Chesemore (1975) reported similar genera of plants consumed by captive-reared, tractable deer during this period. Although the phenological stages of forage species were similar, the diet composition of tractable deer and collected does were not similar. The discrepancy in the diets apparently resulted from site specific differences in edaphic factors, slope, or past land use.

The nutritional value of the does' diet during the winter range green-up period exceeds their metabolic requirements as evidenced by the significant increase in their physical condition indices. An increase in the use of non-browse species and improvement in animal condition occurred during a similar period for the

Railroad Flat deer herd (Browning et al. 1973).

In the early spring migration period the does were moving to higher elevations, and they included a larger percentage of browse in their diets as the grasses and forbs matured. Although the new growth of browses potentially could have met the metabolic demands of the does (Cook 1972), it apparently didn't; as the does consumed a larger quantity of forage, their condition indices declined.

In the late spring migration period, when the does approached their traditional summer home ranges, their diet was heavily dominated by browse. Browse comprised approximately 80% of the diets of tractable deer on a migration corridor during a similar period (Chesemore 1975). In our study, approximately 40% of the does' diet was composed of mountain whitethorn and white fir, neither of which had initiated spring growth. Thus, the does were essentially consuming last year's growth. The lower digestibility of old forage resulted in higher rumen fills. The condition indices continued to decline, indicating that their metabolic requirements were still not being met.

During the summer range green-up period, the additional demands of pregnancy increase the does' metabolic requirements to approximately 1.5 times basal metabolic rate (Moen 1973). The increase in the does' condition indices indicates that they finally obtained a diet that exceeded their metabolic requirements. This included a mixture of grasses, forbs, and emergent browses, particularly mountain whitethorn.

The decreased weight of the rumen-reticulum contents during this period does not necessarily reflect a decrease in forage intake. It probably represents a decrease in the volume capacity of the rumen-reticulum due to the increased volume of the uterus at this time (Maleka 1956). The decrease in the rumen-reticulum volume was probably compensated for by an increased rumen-reticulum turn-over rate owing to the high quality forage consumed (Short 1975).

The early spring migration period coincides with the initiation of the last trimester of gestation, when the does' energetic requirements begin to increase logarithmically (Moen 1973). Thomson and Thomson (1953) and Verme (1963, 1977) have shown that nutritional deficiencies during late gestation can have adverse effects on milk production and birth weights and can lead to an increase in neonatal mortality. Kitts, Cowan, Bandy, and Wood (1956) postulated that a large majority of the neonatal mortality observed in deer may be traced to poor maternal physical condition resulting in delayed or inadequate milk production.

During the combined migration periods, available forage failed to satisfy the does' metabolic requirements. Owing to the maturation or unavailability of herbaceous forage, the does were forced to consume large quantities of browse. The available browse was nutritionally inadequate, and the does depleted their energy reserves. Therefore, we feel that the decline in the physical condition indices of the does during the combined migration periods came at a critical period of gestation and was related to the high neonatal mortality observed in this herd. Results of recent work on caribou, *Rangifer tarandus*, (Dauphiné 1976) and bighorn sheep, *Ovis canadensis*, (Stelfox 1976) have also suggested that poor spring nutrition will increase neonatal mortality in these species.

CONCLUSIONS

The growth rates and ultimate body size of collected does were judged to be normal or above normal for this subspecies of mule deer. Age-specific sizes for

the younger age classes were larger than those reported for other herds of California mule deer. Holl (1976) also found that the growth rates of 3-month-old fawns collected from the North Kings deer herd were equal to those of pen-raised fawns on a high nutritional plane. Thus, it would appear that the nutritional quality of the summer range was not directly governing herd productivity in the North Kings deer herd.

Our data indicate an acute decline in the nutritional plane of the does during the last trimester of gestation, which may have an adverse effect on fetal metabolism or doe milk production. The observed drop in physical condition during migration may have resulted from the unavailability of herbaceous forage and high quality browse during those periods. The deficiency of high quality forage in the does' diets during these periods has resulted largely from the suppression of disturbances on mid-elevation forest and shrubland ranges. Preferred areas that once supported abundant herbaceous forage and young browse plants are now dominated by mature and often impenetrable brush stands. It would be tenuous to quantify the percentage of the herd that is affected by this syndrome. Nevertheless, we feel that this has been an important ecological factor in the decline of this deer herd.

If this hypothesis is true, habitat management can improve fawn survival and increase the population size of the North Kings deer herd. This would entail maintaining the migration corridors and mature brushfields on the summer range at earlier seral stages. Judicious use of fire, logging, and livestock grazing can accomplish this. This should increase the production of nutritious forage on these ranges and provide the deer with sufficient metabolites to meet the demands of late gestation, migration, and subsequent lactation.

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SAFE ZINC AND COPPER LEVELS FROM THE SPRING CREEK DRAINAGE FOR STEELHEAD TROUT IN THE UPPER SACRAMENTO RIVER, CALIFORNIA [1]

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Acid mine discharges in the Spring Creek drainage, collecting behind the Spring Creek Diversion Dam, contribute large quantities of toxic zinc and copper to the upper Sacramento River. Ratios of copper-to-zinc for the Spring Creek Diversion Dam discharge into the Sacramento River fluctuate between 1:2 during storm periods and 1:8 during dry periods. Source control and treatment of the waste for copper removal will result in copper-to-zinc ratios of 1:12 or less in the future. Since the flows into the river of both the waste and the "dilution" water from Shasta Lake can be controlled, dilution factors which will provide for the complete protection of salmonids in the Sacramento River need to be determined and implemented. To determine these factors, long-term (60-day) and short-term (96-hr) bioassays with the waste were conducted on steelhead trout (*Salmo gairdneri*) eggs, alevins, and swim-up fry.

The bioassays indicated that eggs were more resistant than alevins and fry to solutions containing both zinc and copper while solutions containing only zinc affected all stages equally. At the lower copper-to-zinc waste ratio of 1:12, copper was absent in solution at partially toxic levels and toxicity was attributable to zinc alone, while at the higher waste ratio of 1:4, copper was present in sufficient quantities to increase the toxicity of the waste. The incipient lethal levels (10% mortality) for the period from eggs-to-fry were .12 mg/l Zn at the lower waste ratio, and .10 mg/l Zn and .011 mg/l Cu at the higher waste ratio. The incipient lethal level of control fry, those which had not been previously exposed to the waste, was .03 mg/l Zn. The presence of aluminum and iron in the waste apparently did not affect the toxicity of either zinc or copper. "Safe" levels of zinc and copper for steelhead trout are below .03 mg/l and .01 mg/l, respectively.

INTRODUCTION

Acid mine waste from the Spring Creek drainage (Figure 1) has caused numerous kills of anadromous and resident salmonid fishes in the upper Sacramento River between Keswick Reservoir and Cottonwood Creek, California (Prokopovich 1965; Calif. Dept. Fish and Game, Region 1, unpublished data; Nordstrom 1977). Of the anadromous salmonid fishes which have been affected, steelhead trout and chinook salmon, *Oncorhynchus tshawytscha,* are particularly important because of their recreational value; chinook salmon are also commercially valuable.

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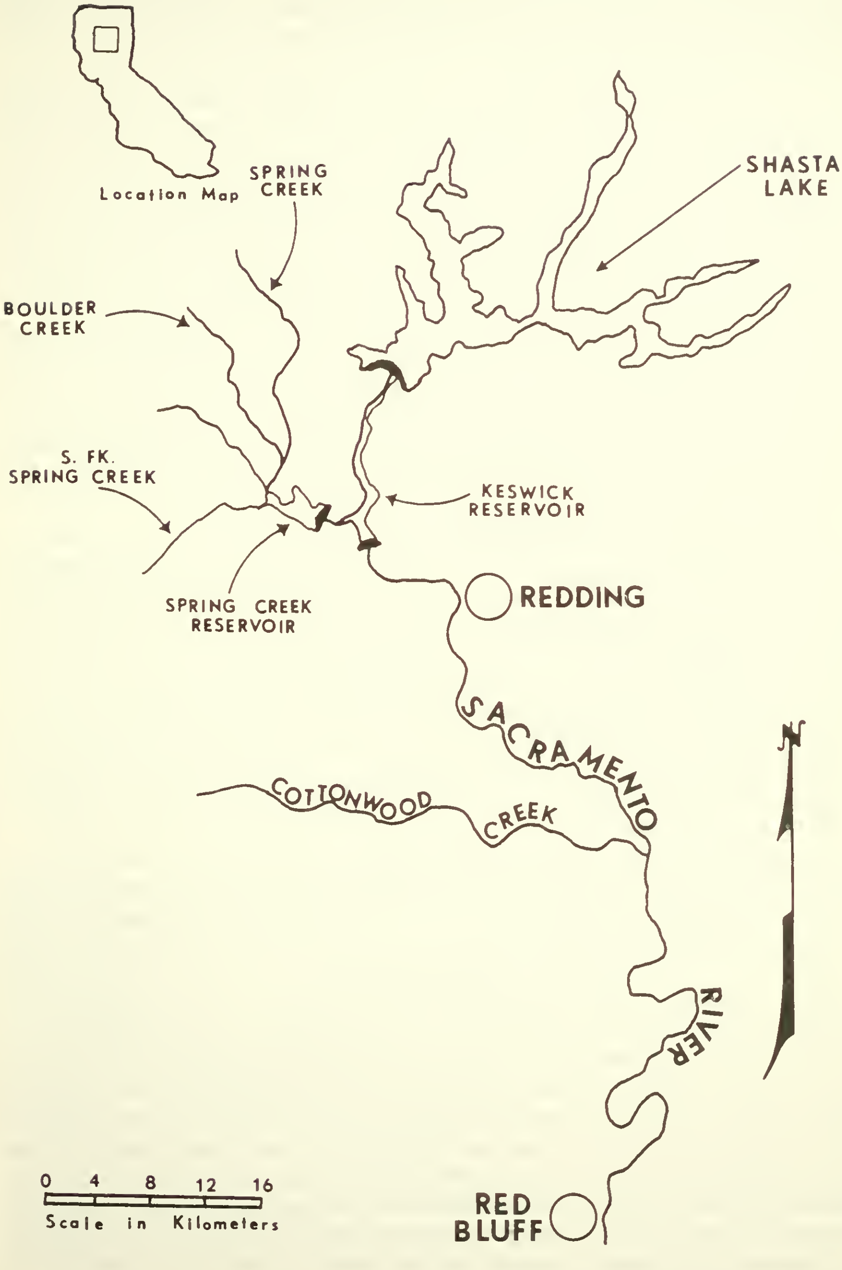

FIGURE 1. Location of Spring Creek drainage, Upper Sacramento River basin, California.

The acid mine discharge originates from both abandoned and operating mines, waste dumps, and naturally exposed sulfide mineral deposits. The waste contains large quantities of zinc, copper, aluminum, iron, and other heavy metals in smaller concentrations. Of the four most abundant metals, zinc and copper are extremely toxic to salmonids.

Although the toxicities of zinc (Colorado Game, Fish, and Parks 1971; Nehring and Goettl 1974; Solbe 1974; Zitko and Carson 1977), copper (Sprague and Ramsey 1965; Hazel and Meith 1970; McKim and Benoit 1971), and their combinations (Lloyd 1961; Sprague 1964; Sprague, Elson, and Saunders 1965; Thomsen, Hazel, and Meith 1970) have been well investigated and summarized (Chapman 1973; Finlayson and Rectenwald 1978), none have previously identified the additive effects of zinc and copper and other metals from an acid mine waste on eggs, alevins, and swim-up fry of steelhead trout or chinook salmon. The toxicities of aluminum (Freeman and Everhart 1971; Freeman 1973) and iron (Davis 1970; Sykora, Smith, and Synak 1972; Becker and Keller 1973) have been investigated but not in conjunction with other toxic metals such as zinc and copper. It is the dissolved fractions of these metals, ions in solution, which produce the toxic reactions in fish. Metals in solution are in equilibrium with their oxide and hydroxide precipitates or colloids, and this ionic balance is typically dependent on pH and water hardness.

Problems with this acid mine discharge are not new. The waste polluted the Sacramento River prior to the construction of Shasta Dam in 1944 and Keswick Dam in 1950. However, when Sacramento River streamflow was uncontrolled, flood flows coincided with those of the tributaries, thereby diluting Spring Creek runoff and probably diluting the waste to levels tolerable to fish (U.S. Fish and Wildlife Service 1959). However, more devastating problems arose after Shasta Dam was completed because, while "dilution" water in the upper Sacramento River Basin was stored in Lake Shasta during the heavy rains, the runoff from Spring Creek was left to enter the Sacramento River unobstructed. Hence, the toxic runoff from Spring Creek contributed a greater percentage of the total Sacramento River flow.

Since 1963 the waste has been collected in Spring Creek Reservoir and metered into Keswick Reservoir on the Sacramento River. The flow of the waste through the Spring Creek Diversion Dam is determined by the amount of "dilution" water available (Nordstrom 1977), the "dilution" water originating from Shasta Lake. This water quality management program has been based on the "tolerable" dilution factors calculated by Lewis (1963). He formulated two separate release schedules, based on two separate dilution factors using time-of-year and copper concentrations in the waste as discharge criteria. One release schedule was calculated for May through December, and the other for January through April. Lewis (1963) developed these factors from toxicity data obtained by exposing juvenile rainbow trout (*Salmo gairdneri*) and chinook salmon to the waste during 96-hr static bioassays. Although the release schedules have provided a margin of protection for salmonids in the Sacramento River, complete protection has probably not been provided because of questions not considered in the design of the bioassays and the problems this created in the interpretation of the results. These problems are:

1) juvenile fish were used in the bioassays; however, it has been demonstrated that younger and more sensitive life cycle stages of salmonids exist;
2) the bioassays did not consider periods of exposure beyond 96-hr, although

greater periods of exposure undoubtedly exist in the river;

3) copper was the only toxic element considered in the bioassays; however, it has been recently demonstrated that zinc may be the only toxic element remaining in solution below Keswick Dam after the dilution of the waste to partially toxic levels (D. Wilson, Associate Water Quality Biologist, Calif. Dept. Fish and Game, pers. commun.);
4) static bioassays were used which did not consider the loss of copper and zinc from solution with time; therefore, the tests were not representative of a continuous discharge;
5) total copper, not dissolved copper, was measured as the toxic substance in the bioassays; however, it has been demonstrated that it is the dissolved fractions of total copper and zinc which produce the toxic reactions in fish;
6) the release schedules were based on the time-of-year runoff and total copper concentrations occurring in the waste, not on dissolved copper and zinc concentrations occurring in the waste or the river.

The quality of the acid mine waste has also changed since the development of the release schedules. Much of the copper contained in the waste is now removed by several copper cementation plants located throughout the drainage (Nordstrom 1977). All metals, with the exception of copper, remain in the same ratio to each other even though their concentrations decrease during storm periods and increase during dry periods. Copper concentrations, however, increase in ratio to the other metals during storm periods, and hence, the copper-to-zinc ratios of the waste normally fluctuate between 1:2 and 1:12 for wet and dry seasons, respectively (D. Wilson, pers. commun.).

The objective of our study was to gather accurate and relevant information which would answer the questions not considered by Lewis (1963) and those created by the recent developments in the drainage (Nordstrom 1977). This information is necessary to permit the calculation of new release schedules which should provide for complete protection of salmonids below Keswick Dam. The general approach of our study was to expose newly fertilized eggs of steelhead trout to different concentrations of two copper-to-zinc ratio (1:4 and 1:12) wastes and to raise the individuals to the swim-up fry stage in the same concentrations. We also raised cohorts of the above individuals to swim-up fry in waste-free water for use in bioassay testing at the swim-up fry stage. This was done to determine if prior exposure of the fry affects their sensitivity to the waste.

MATERIALS AND METHODS

The acid mine waste used in the study was obtained from Boulder Creek, a tributary to Spring Creek (Figure 1). Most of the heavy metal pollutant load, with the exception of copper, originates from Boulder Creek (Nordstrom 1977). Because of the large quantity of iron (ca. 1%) present in the waste (Table 1), which precipitates out as ferric hydroxide and ferric oxide (collectively known as rust) upon dilution, we diluted the waste to 25% of original strength with distilled water and then readjusted the copper and zinc concentrations using reagent grade copper sulfate ($CuSO_4 \cdot 5H_2O$) and zinc sulfate ($ZnSO_4 \cdot 7H_2O$). The iron content was reduced by 75% because the original iron concentration would coat and smother the developing eggs with a heavy rust precipitate.

Preliminary investigations at the Department's Water Pollution Control Laboratory (WPCL) revealed an antagonistic relationship between aluminum and

zinc (Finlayson, unpublished data, 1977). For example, the 96-hr LC50 of a zinc sulfate stock solution to juvenile rainbow trout was .14 mg/l Zn. No acute toxicity to rainbow trout could be found with aluminum sulfate at concentrations below 100 mg/l A1. However, when zinc and aluminum were present together at a ratio of 1:2, the 96-hr LC50 of zinc sulfate was increased to .52 mg/l Zn. The polymerization of aluminum hydroxide into large colloidal particles occurs at near-neutral (6.0–8.0) pH (Hem 1968), and this process was witnessed during the preliminary tests. The incorporation of zinc ions into the aluminum hydroxide colloids would effectively remove zinc from solution and could explain the antagonistic effects of aluminum on zinc toxicity. Since Spring Creek waste generally contains zinc and aluminum at a ratio of 1:1.5 (D. Wilson, pers. commun.), we also added reagent grade aluminum sulfate [$A1_2(SO_4)_3{\cdot}16H_20$] back to the waste.

TABLE 1. Chemical Composition of Boulder Creek Waste and Adjusted Stock Toxicants Used in Bioassays (Ratios as copper : zinc : aluminum)

		Adjusted Boulder Creek wastes	
	Boulder Creek waste	*1:4:6 Stock toxicant*	*1:12:18 Stock toxicant*
Copper (mg/l)	18.6	387. (5) *	120. (5)
Zinc (mg/l)	1490.	1650. (5)	1560. (5)
Aluminum (mg/l)	1487.	2720. (5)	2410. (5)
Iron (mg/l)	9490.	2940. (4)	2690. (4)

* Sample sizes in parenthesis.

Two copper-to-zinc-to-aluminum ratio wastes were tested in both chronic (60-day) and short-term (96-hr) bioassays. In one waste, the ratio was adjusted to 1:4:6, and in the other waste, the ratio was adjusted to 1:12:18. The concentrations of zinc and aluminum were held constant at approximately 1600 and 2400 mg/1, respectively, and copper concentrations were adjusted by adding copper back to the waste at the appropriate ratio. During the bioassays, the waste stock solutions were replenished every 14 days, and each new solution was analyzed for copper, zinc, aluminum, and iron as a quality control measure (Table 1).

The wastes were diluted in a geometric series (100, 56, 32, 18, 10%) and continually delivered to the developing eggs, alevins, and fry using modified Mount and Brungs (1967) type plexiglass proportional diluters (Figure 2) designed and constructed by us at WPCL. Water from the American River, a tributary to the Sacramento River was filtered and used for dilution. Since the American and Sacramento rivers are of similar pH and water hardness, similar dissolved fractions of the metals would also be expected in the Sacramento River and in our bioassay waste concentrations. Immediately prior to entry into the proportional diluters, the concentrated wastes were prediluted to .06 and .1% of original strength for the 1:4:6 ratio and 1:12:18 ratio wastes, respectively. These initial dilutions constituted the 100% concentrations used in the geometric series of dilutions. Predilution was accomplished using a peristaltic pump and adjustable flow meter to pump into the plexiglass predilution chamber along with a metered supply of dilution water (Figure 2). After mixing in the predilution chamber, the waste then flowed through a plexiglass filtering chamber

packed with spun glass for removal of residual ferric oxide and hydroxide precipitate. The spun glass was replaced weekly. After filtration, the prediluted waste then flowed into the toxicant cells of the proportional diluters.

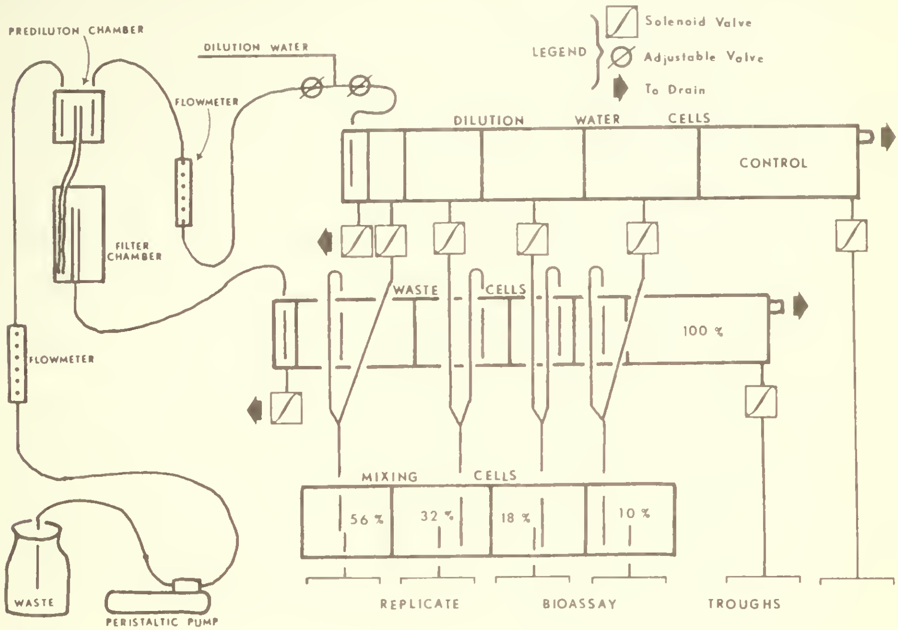

FIGURE 2. Schematic diagram of waste predilution system and modified Mount and Brungs type proportional diluter.

The waste concentrations and control dilution water from the proportional diluters were divided in two and supplied to replicate plexiglass bioassay troughs. The troughs were 92-cm long by 13-cm wide, with the water level adjusted to a depth of 10 cm by a standpipe. The troughs were subdivided into five compartments by alternating baffles which allowed for the complete circulation of the diluted wastes over the developing eggs, alevins, and fry. The fertilized eggs were incubated in egg baskets, three baskets per trough. The egg baskets were perforated polyethylene plastic jars, 6.5-cm in diameter and 9-cm high. The troughs had a volume of approximately 12 liters, and approximately 500 ml of the diluted waste was supplied to each trough every 7 minutes. The volume of each trough was replenished every 2.8 hours.

Continual-flow bioassays using standard methods (Peltier 1977) were carried out at WPCL with freshly fertilized steelhead trout eggs and the resulting alevins and swim-up fry. All concentrations were tested in replicate. The eggs were obtained by dry spawning three female and two male adult fish on 10 February 1978 at the Department's Nimbus Hatchery on the American River.

Following dry spawning, the eggs were segregated and placed in the different concentrations of the diluted wastes and allowed to water-harden. The "controls" were water-hardened in filtered American River water. Water-hardening took place in 2-liter glass beakers and lasted 3 hours. After water-hardening, 50 eggs were hand counted and carefully floated into each egg basket (150 eggs

per trough or 300 eggs per concentration). "Control" eggs which were not used in the chronic bioassay were deposited in several, square, 10-liter, overflowing plexiglass aquaria, placed in the dark with a supply of flowing water, and allowed to hatch and develop into swim-up fry. These "control" swim-up fry were used later in short-term bioassays with the same equipment and concentrations that were used in the chronic bioassays.

The 60-day chronic bioassays began on 10 February 1978 with fertilized steelhead eggs and ended on 11 April 1978 when individuals were at the swim-up fry stage. The 96-hour acute bioassays began with the additional "control" swim-up fry on 24 April and ended on 28 April 1978.

During the bioassays, water samples were collected twice weekly from the troughs for analyses of both total and dissolved copper, zinc, aluminum, and iron. Concentrations of these metals were determined by atomic absorption analysis (American Public Health Association 1975). Samples for dissolved metals were collected by filtration through Gelman ® type A-E glass-fiber filters. All samples were preserved with nitric acid and hydrochloric acid. Dissolved oxygen, pH, and temperature were determined in each trough three times a week, whereas water hardness was determined only once a week.

Deaths were not recorded in the chronic bioassays until the embryos left the "tender" stage and entered the "eyed" stage. Once the "eyed" stage was entered, dead embryos could be safely removed from the egg baskets. The dead were recorded and removed three times a week. Additionally, the ferric oxide and hydroxide precipitate which formed in the bioassay troughs was carefully suctioned away with a turkey baster to avoid disturbing the developing eggs.

Mortality estimates were calculated from the following equations:

(1) $M_e = (1 - S_{xe}/S_{ce})\ 100$

where M_e is mortality of eggs, S_{xe} is the survival of eggs from fertilization to hatch in concentration X, and S_{ce} is the survival of control eggs from fertilization to hatch in waste-free water.

(2) $M_a = (1 - S_{xa}/S_{ca})\ 100$

where M_a is mortality of alevins, S_{xa} is the survival of newly hatched alevins to swim-up fry in concentration X, and S_{ca} is the survival of newly hatched control alevins to swim-up fry in waste-free water.

(3) $M_t = (1 - S_{xt}/S_{ct})\ 100$

where M_t is mortality for the period of fertilization to swim-up fry, S_{xt} is the survival from fertilization to swim-up fry in concentration X, and S_{ct} is the survival from fertilization to swim-up fry in waste-free water.

(4) $M_f = (1 - S_{xf}/S_{cf})\ 100$

where M_f is mortality of "control" swim-up fry, S_{xf} is the survival of the "control" swim-up fry in concentration X during the 96-hr exposure, and S_{cf} is the continued survival of the "control" swim-up fry during the 96-hr exposure in waste-free water.

Standard log-probit (concentration-mortality) analysis (APHA 1975) was used to calculate the $LC50_e$, $LC50_a$, $LC50_t$, and $LC50_f$ (concentration producing 50% mortality) and the ILL_e, ILL_a, ILL_t, and ILL_f (incipient lethal level; concentration producing 10% mortality) for the wastes. Heavy metal concentrations at the LC50's and ILL's were extrapolated from known metal concentrations above and below these levels.

RESULTS

60-Day Chronic Bioassay

The bioassay test concentrations had a pH range of 6.3 to 7.5. Water hardness of the test concentrations varied from 34 to 65 mg/l $CaCO_3$. Water temperatures during the bioassays were between 9 and 10 C and dissolved oxygen was near saturation at all times.

The concentrations of total metals present in the 1:4:6 ratio and 1:12:18 ratio waste bioassays increased with increased waste concentrations (Appendices 1 and 2, respectively). Dissolved zinc concentrations in the 1:4:6 ratio waste bioassay ranged from 1.15 to <.01 mg/l for .067% waste and control, respectively; dissolved copper concentrations ranged from .15 to <.01 mg/l for the same concentrations (Appendix 1). Dissolved aluminum ranged from .07 to <.01 mg/l with the highest concentrations occurring in .021 and .012% wastes and the lowest concentrations occurring in .037 and .067% wastes and control. Dissolved iron ranged from .80 to .15 mg/l for the .067% waste and control, respectively. The dissolved concentrations of zinc, copper, and iron averaged 86.2, 42.1, and 40.7% of total concentrations, respectively.

Dissolved zinc concentrations in the 1:12:18 ratio waste bioassay ranged from 1.25 to <.01 mg/l for .100% waste and control, respectively; dissolved copper concentrations ranged from .042 to <.01 mg/l for the same concentrations (Appendix 2). Dissolved aluminum ranged from .18 to <.01 mg/l with the highest concentrations occurring in .032% waste and the lowest occurring in .056 and .100% wastes and control. Dissolved iron ranged from 1.12 to .14 mg/l for .100% waste and control, respectively. The dissolved concentrations of zinc, copper, and iron averaged 75.0, 30.3, and 39.6% of total concentrations, respectively.

Estimates of M_e, M_a, and M_t increased with increased concentration in both the 1:4:6 ratio (Table 2) and 1:12:18 ratio (Table 3) wastes. Complete mortality (100%) occurred in the highest waste concentrations tested while minimal mortality (8.2 to 18.2%) occurred in the lowest waste concentrations tested. Survival of the control eggs-to-fry ranged from 88.0 to 94.7%.

The $LC50_e$ and $LC50_a$ of the 1:4:6 ratio waste were .017 and .010% waste, respectively (Table 4). Zinc and copper concentrations at these two levels were .30 mg/l Zn and .035 mg/l Cu, and .19 mg/l Zn and .021 mg/l Cu, respectively. Eggs were more resistant to zinc and copper concentrations than were alevins in this ratio waste. Similar differences between the sensitivities of eggs (ILL_e) and alevins (ILL_a) to zinc and copper occurred at the incipient lethal level. The $LC50_t$ and ILL_t were .009 and .006% waste, respectively, and resembled the $LC50_a$ and ILL_a, thereby suggesting that the developmental period from alevins-to-fry was more sensitive to copper and zinc concentrations than the developmental period from eggs-to-hatch.

The $LC50_e$ and $LC50_a$ of the 1:12:18 ratio waste were .035 and .042% waste, respectively, with zinc concentrations of .42 and .52 mg/l, respectively (Table 4). Dissolved copper was absent at these levels. Eggs were more sensitive at the LC50 level to zinc than were fry in this ratio waste. However, the ILL_e and ILL_a were .018 and .010% waste, respectively, with zinc concentrations of .23 and .14 mg/l, respectively. Even though fry were more resistant to zinc than eggs at the LC50 level, the opposite was true at the ILL. The $LC50_t$ and ILL_t were .032 and .010% of waste, respectively. The $LC50_t$ resembled the $LC50_e$ but the ILL_t resembled the ILL_a thereby suggesting that zinc concentrations, in the absence of copper, equally affect the developing egg and alevin.

TABLE 2. Mortality Estimates for Steelhead Eggs Raised to Swim-Up Fry Stage in Five Concentrations of the 1:4:6 Copper-to-Zinc-to-Aluminum Ratio Waste

Concentration of waste		Percent mortality Eggs[b] (M_e)	Alevins[c] (M_a)	Total[d] (M_t)
.067%	(1)[a]	100	–	100
	(2)	100	–	100
.037%	(1)	98.6	100	100
	(2)	98.6	100	100
.021%	(1)	66.2	100	100
	(2)	63.2	100	100
.012%	(1)	24.6	69.9	77.3
	(2)	23.6	80.6	85.2
.007%	(1)	2.2	6.6	8.3
	(2)	6.7	12.4	18.2

[a] Numbers in parentheses indicate replicates.
[b] Survival of control eggs ranged from 92.0 to 98.7%.
[c] Survival of control alevins ranged from 95.7 to 97.3%.
[d] Total survival of controls to swim-up fry stage ranged from 88.0 to 94.7%.

TABLE 3. Mortality Estimates for Steelhead Eggs Raised to Swim-Up Fry Stage in Five Concentrations of the 1:12:18 Copper-to-Zinc-to-Aluminum Ratio Waste

Concentration of waste		Percent mortality Eggs[b] (M_e)	Alevins[c] (M_a)	Total[d] (M_t)
.100%	(1)[a]	100	–	100
	(2)	100	–	100
.056%	(1)	94.4	100	100
	(2)	97.3	100	100
.032%	(1)	25.0	33.9	50.4
	(2)	18.4	38.8	51.8
.018%	(1)	2.8	3.9	6.7
	(2)	17.6	19.9	41.0
.010%	(1)[e]	51.8	38.6	90.4
	(2)	2.0	9.5	10.0

[a] Numbers in parentheses indicate replicates.
[b] Survival of control eggs ranged from 94.0 to 98.7%.
[c] Survival of control fry ranged from 93.9 to 96.1%.
[d] Total survival of controls to swim-up fry stage ranged from 90.0 to 92.7%.
[e] This aquaria suffered an extreme outbreak of fungus and was not used in the calculation of bioassay statistics.

96-Hr Acute Bioassay

The bioassay test concentrations had a pH range of 6.5 to 7.6. Water hardness of test concentrations ranged from 25 to 60 mg/l $CaCO_3$. Water temperatures during the bioassays were between 10 and 11C, and dissolved oxygen was near saturation at all times.

The concentrations of total metals present in the 1:4:6 ratio and 1:12:18 ratio waste bioassays increased with increased waste concentrations (Appendices 3 and 4, respectively). Dissolved zinc concentrations in the 1:4:6 ratio waste bioassay ranged from 1.21 to $<.01$ mg/l for .067% waste and control, respectively; dissolved copper concentrations ranged from .14 to $<.01$ mg/l for the same concentrations (Appendix 3). Dissolved aluminum was consistently $<.01$ mg/l for all waste concentrations and control; dissolved iron ranged from .56 to

TABLE 4. Summary of Statistics for 60-Day Bioassays on 1:4:6 and 1:12:18 Copper-to-Zinc-to-Aluminum Ratios of Acid Mine Wastes. Statistics represent means based on replicates.

	Eggs-to-hatch				*Hatch-to-swim-up fry*				*Total*			
	$LC50_e$		*ILL_e*		*$LC50_a$*		*ILL_a*		*$LC50_t$*		*ILL_t*	
	1:4:6	*1:12:18*	*1:4:6*	*1:12:18*	*1:4:6*	*1:12:18*	*1:4:6*	*1:12:18*	*1:4:6*	*1:12:18*	*1:4:6*	*1:12:18*
Concentration of waste (%)	.017	.035	.009	.018	.010	.042	.007	.010	.009	.032	.006	.010
Total zinc (mg/l)	.35	.61	.20	.29	.22	.72	.17	.18	.20	.56	.14	.18
Dissolved zinc (mg/l)	.30	.43	.17	.23	.19	.52	.14	.14	.17	.39	.12	.14
Total copper (mg/l)	.073	.039	.043	.019	.046	.050	.036	< .01	.043	.035	.033	< .01
Dissolved copper (mg/l)	.035	< .01	.019	< .01	.021	< .01	.014	< .01	.019	< .01	.012	< .01

.11 mg/l for .067% waste and control, respectively. The dissolved concentrations of zinc, copper, and iron averaged 81.5, 42.3, and 46.2% of total concentrations, respectively.

Dissolved zinc concentrations in the 1:12:18 ratio waste bioassay ranged from 1.18 to <.01 mg/l for .100% waste and control, respectively; dissolved copper concentrations ranged from .042 to <.01 mg/l for the same concentrations. Dissolved aluminum was consistently <.01 mg/l for all waste concentrations and control; dissolved iron ranged from .57 to .08 mg/l for .100% waste and control, respectively. The dissolved concentrations of zinc, copper, and iron averaged 74.5, 37.1, and 43.1% of total concentrations, respectively.

Estimates of M_f increased with increased waste concentrations of both the 1:4:6 ratio and 1:12:18 ratio wastes (Table 5). Complete mortality (100%) occurred at the three highest concentrations tested in both ratio wastes. Survival of the controls ranged from 98 to 100%.

TABLE 5. Mortality estimates for Steelhead Swim-up Fry Exposed for 96-hr to Five Concentrations of 1:4:6 and 1:12:18 Copper-to-Zinc-to-Aluminum Ratio Wastes

1:4:6 Concentration of waste[a]	*1:4:6* Percent[b] mortality (M_f)	*1:12:18* Concentration of waste[a]	*1:12:18* Percent[c] mortality (M_f)
.067% (1)[a]	100	.100% (1)	100
(2)	100	(2)	100
.037% (1)	100	.056% (1)	100
(2)	100	(2)	100
.021% (1)	100	.032% (1)	100
(2)	100	(2)	100
.012% (1)	91	.018% (1)	57
(2)	96	(2)	64
.007% (1)	95	.010% (1)	42
(2)	96	(2)	42

[a] Numbers in parentheses indicate replicates.
[b] Survival of controls was 100%.
[c] Survival of controls was 98%.

Estimates of M_f in all 1:4:6 ratio waste concentrations were greater than 91% (Table 5) which precluded the calculation of a $LC50_f$ or an ILL_f (Table 6). The mean M_f in the .007% waste, which was the lowest concentration tested, was 95.5%, and zinc and copper at this level were .14 and .012 mg/l, respectively. The $LC50_f$ of the 1:12:18 ratio waste was .013% waste; zinc and copper at this level were .18 and <.01 mg/l, respectively (Table 6). The ILL_f was .003% waste with zinc and copper at .03 and <.01 mg/l, respectively.

TABLE 6. Summary of Statistics for 96-hr Bioassays on 1:4:6 and 1:12:18 Copper-to-Zinc-to-Aluminum Ratios of Acid Mine Wastes. Statistics represent means based on replicates.

	60-Day swim-up fry			
	$LC50_f$		*ILL_f*	
	1:4:6	*1:12:18*	*1:4:6*	*1:12:18*
Concentration of waste (%)	<.007	.013	–	.003
Total zinc (mg/l)	<.22	.32	–	.06
Dissolved zinc (mg/l)	<.14	.18	–	.03
Total copper (mg/l)	<.034	.016	–	.010
Dissolved copper (mg/l)	<.012	<.01	–	<.01

DISCUSSION

Bioassays were conducted on two copper-to-zinc-to-aluminum ratio acid mine wastes. Both 60-day chronic and 96-hr acute exposures were investigated with fertilized steelhead eggs to the swim-up fry stage, and swim-up fry, respectively. The toxicity data demonstrated that swim-up fry not previously exposed to the waste were more sensitive to the waste than swim-up fry which had been previously exposed to the waste. The incipient lethal level of the 1:12:18 ratio waste during the 60-day exposure was .14 mg/l Zn, while that during the 96-hr exposure was .03 mg/l Zn. The LC50 of the 1:4:6 ratio waste during the 60-day exposure was .17 mg/l Zn and .019 mg/l Cu, while that during the 96-hr exposure was $<$.14 mg/l Zn and $<$.012 mg/l Cu. This indicates that acclimation to zinc and copper concentrations in the waste was occurring during embryonic and alevin development.

However, although we planned to test the sensitivities of waste-exposed and waste-unexposed fry, the swim-up fry used in the 96-hr tests were further developed (free-swimming) than the swim-up fry at the end of the 60-day test (not free-swimming). Hence, we probably were not testing identical life cycle stages. Chapman (Dr. Gary Chapman, Western Fish Toxicology Station, National Environmental Research Center, Corvallis, Oregon, pers. commun.) found salmonid swim-up fry to be the most sensitive life cycle stage to heavy metals. Hence, our data may be demonstrating differences between the sensitivities of two life cycle stages as well as an acclimation to heavy metals.

When soluble copper was present in the diluted waste (1:4:6 ratio waste) the eggs were more resistant to both copper and zinc concentrations than were the resulting alevins and fry. Hazel and Meith (1970), testing a stock solution of copper sulfate, found similar differences between the sensitivities of chinook salmon eggs and fry to copper. Conversely, differences between the sensitivities of eggs and fry to zinc were not apparent when copper was absent in the diluted waste (1:12:18 ratio waste). Hence, although copper determinately affects fry, zinc appears to equally affect the eggs and fry. Regardless, our data and that of Hazel and Meith (1970) and Chapman (pers. commun.) show that swim-up fry are as sensitive or more sensitive than eggs to zinc and copper concentrations.

The LC50's of zinc (in the absence of copper) for steelhead fry ranged from .18 to .39 mg/l and the ILL's ranged from .03 to .14 mg/l. Thomsen et al. (1970), testing a stock solution of zinc sulfate to juvenile steelhead stock from Nimbus Hatchery, found the 96-hr LC50 of zinc to be .12 mg/l. Our range of zinc ILL's is in excellent agreement with that of Thomsen et al. (1970), who found the 96-hr ILL of zinc to juvenile steelhead to be .06 mg/l. It is surprising that our data agree as well as they do since the toxicity of zinc to rainbow trout has been reported to vary considerably (.24 to .83 mg/l) at the 96-hr LC50 level (Colorado Game, Fish, and Parks 1971). Based on our estimated ILL's and that of Thomsen et al. (1970), concentrations of zinc (in the absence of copper) which will completely protect steelhead trout fry are below .03 mg/l. The U.S. Environmental Protection Agency (1976) recommends a "safe" concentration of zinc at .01 times the 96-hr LC50 for the species in question. Using this criterion and our LC50 estimates for zinc, "safe" concentrations of zinc (in the absence of copper) for steelhead fry are between .0018 and .0039 mg/l.

The LC50's of copper and zinc for steelhead fry ranged between $<$.14 mg/l

Zn and <.012 mg/l Cu, and .17 mg/l Zn, and .018 mg/l Cu. The ILL estimates during the 60-day test were .12 mg/l Zn and .012 mg/l Cu. No ILL could be determined for the 1:4:6 ratio waste in the 96-hr test because of the high mortality (mean of 95.5%) which occurred in the lowest waste concentration (.007%) tested. For juvenile steelhead exposed to stock solutions containing both zinc and copper sulfates, Thomsen et al. (1970) found the 96-hr LC50 to be .16 mg/l Zn and .034 mg/l Cu, and the ILL to be .10 mg/l Zn and .01 mg/l Cu. Based on our estimated ILL's and that of Thomsen et al. (1970), concentrations of zinc and copper which will completely protect steehlead trout fry are below .03 mg/l and .01 mg/l, respectively. The U.S. EPA (1976) recommends a "safe" concentration of copper at .1 times the 96-hr LC50 for the species in question. Using this criterion, the one given for zinc above, and our LC50 estimates for zinc and copper, "safe" concentrations of zinc and copper for steelhead fry are between <.0014 and .0017 mg/l Zn and <.0012 and .0018 mg/l Cu.

Our zinc and copper toxicity data agree well with that of Thomsen et al. (1970) who tested toxicant stock solution containing only zinc and copper, not an actual acid mine waste. The Spring Creek acid mine waste contains other metals, including aluminum and iron, which could be toxic. Freeman and Everhart (1971) found the threshold of acute toxicity around 1.5 mg/l soluble aluminum. The U.S. EPA (1976) reports that soluble concentrations of iron below 1.0 mg/l are "safe" for all freshwater aquatic life and Davis (1970) states that iron is probably not directly harmful to fish except it may become a nuisance when precipitated. Sykova et al. (1970) found that increased turbidity caused by an iron precipitate makes fish food items harder to see and therefore, decreases fish growth. Hence, we must dismiss both aluminum and iron toxicity in our bioassays since the highest soluble concentrations measured for the two metals in all the tests were .18 mg/l and 1.12 mg/l, respectively. Although we expected aluminum to act antagonistically on zinc toxicity, we must dismiss this hypothesis also because of the low zinc LC50's and ILL's found. Perhaps iron, rather than zinc, co-precipitates with aluminum in the acid mine waste. The incorporation of zinc into aluminum polymers may occur only when these two elements are present.

Our data demonstrated that both iron and aluminum rapidly precipitate out of solution with dilution and hence, increase in pH. Dissolved iron concentrations are quite low (ca. 0.3 mg/l) in Keswick Reservoir, although the iron concentrations of the Spring Creek Diversion Dam discharge average 400 mg/l (D. Wilson, pers. commun.). Low concentrations of dissolved aluminum would also be expected in Keswick Reservoir. Hence, even though large concentrations of iron and aluminum occur in the Spring Creek waste, dilution and precipitation cause the dissolved concentrations of the two metals to be so low that they do not exist in toxic concentrations. The presence of iron and aluminum in the waste apparently does not affect the toxicity of zinc and copper since our data agree reasonably well with those of Thomsen et al. (1970).

The release schedules calculated by Lewis (1963) allow total copper concentations in the Sacramento River below Keswick Dam to reach .025 and .045 mg/l for the periods of May through December, and January through April, respectively. Our data show dissolved copper averaged 38.2% of the total copper concentration. Thus, the criteria established by Lewis (1963) allow dissolved

copper concentrations to reach .010 mg/l during May through December, and .017 mg/1 during January through April. We found steelhead fry mortality occurring at dissolved copper concentrations less than .01 mg/l. Hence, the release schedules calculated by Lewis (1963) do not provide for complete protection from copper toxicity.

Using the waste dilution factors calculated by Lewis (1963), we were able to estimate the concentrations of dissolved zinc occurring in the Sacramento River below Keswick Dam as a result of the scheduled releases from Spring Creek Reservoir. In our calculations, we assumed the total copper and zinc concentrations of the undiluted Spring Creek Reservoir discharge to vary between 2 and 10 mg/l Cu, and 10 and 90 mg/l Zn (D. Wilson, pers. commun.), and the dissolved concentrations of zinc, equivalent to the mean found in our tests, were 80.7% of total zinc concentrations. For May through December, the waste would have to be diluted between .25 and 1.2% of original strength to attain the .025 mg/1 total copper criterion in the Sacramento River; these dilutions would allow between .02 and .91 mg/l dissolved zinc, respectively, in the Sacramento River. Likewise for the period of January through April, the waste would have to be diluted between .45 and 2.2% of original strength to attain the .045 mg/l total copper criterion in the Sacramento River. These dilutions would allow between .04 and 1.60 mg/l dissolved zinc, respectively, in the Sacramento River. We found the ILL of swim-up fry to be .03 mg/l Zn, which is in the middle of the range of minimal zinc concentrations (.02–.04 mg/l) allowed by these calculations. Even if our calculations depict the worst-case situation of the zinc pollution in the Sacramento River, it is evident that complete protection of steelhead fry from zinc toxicity has not been provided by the release schedules of Lewis (1963).

With respect to "safe" levels of zinc and copper in the Sacramento River, concentrations of both metals must be kept below .03 and .01 mg/l, respectively, in order to afford protection of steelhead populations below Keswick Dam. Allowable levels of zinc and copper in excess of these should only be considered as "interim". The release schedules from the Spring Creek Reservoir should be calculated so that, after dilution in Keswick Reservoir, "safe" levels of zinc and copper are released from Keswick Dam into the Sacramento River. It should be noted that .03 mg/l zinc and .01 mg/l copper are near the current practical detection limits of most acceptable analytical techniques, and therefore, actual "safe" levels below these cannot be determined or detected accurately with the present technology.

Today, with even less copper present in the outflow of Spring Creek than was present 15 years ago, the old release schedules provide for even less protection from zinc toxicity. This is because of lower concentrations of copper present in the Spring Creek waste which permits less dilution, and hence higher zinc concentrations occur in the Sacramento River. We have shown that copper and zinc have the same order of toxicity, but zinc concentrations are typically present in the waste at one order of magnitude greater than that of copper. Additionally, the dissolved fraction of zinc is between two and three times greater than that of copper. New release schedules need to be formulated using the "safe" levels of both zinc and copper as criteria but with the most attention given to zinc. Additionally, concentrations of zinc and copper need to be meas-

ured in both the waste and in the river if new waste release schedules are to be accurately implemented.

Studies need to be conducted with chinook salmon eggs and fry to extend our knowledge of zinc and copper toxicity to salmonids in the Sacramento River. Chinook are more abundant than steelhead in the main stem of the Sacramento River below Keswick Dam. Moreover, because the Spring Creek Diversion Dam presently overflows during heavy precipitation, additional studies need to be carried out with salmonid fry to identify the effects of high waste concentrations of short duration.

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APPENDIX 1—Concentrations of Zinc, Copper, Aluminum, and Iron in Bioassay Aquaria During 60-day Bioassay on 1:4:6 Copper-to-Zinc-to-Aluminum Ratio Waste

	Concentration of waste	*Zn (mg/l)*	*Cu (mg/l)*	*Al (mg/l)*	*Fe (mg/l)*
	Total (1) [a]	1.41 (.42) [b]	.34 (.12)	1.64 (1.04)	2.70 (1.70)
.067%	Dissolved	1.14 (.10)	.15 (.048)	<.01	.80 (.32)
	Total (2)	1.35 (.15)	.42 (.20)	1.73 (.92)	3.21 (1.03)
	Dissolved	1.15 (.10)	.15(.042)	<.01	.67 (.30)
	Total (1)	.68 (.21)	.14 (.072)	.84 (.60)	1.50 (.33)
.037%	Dissolved	.63 (.03)	.059 (.009)	<.01	.25 (.47)
	Total (2)	.66 (.19)	.14 (.069)	.80 (.61)	1.43 (.31)
	Dissolved	.61 (.03)	.052 (.018)	<.01	.36 (.07)
	Total (1)	.42 (.07)	.10 (.042)	.49 (.31)	1.11 (.30)
.021%	Dissolved	.37 (.02)	.043 (.012)	.07 (.13)	.37 (.12)
	Total (2)	.42 (.09)	.091 (.053)	.50 (.35)	1.11 (.26)
	Dissolved	.36 (.02)	.042 (.011)	.03 (.07)	.35 (.10)
	Total (1)	.26 (.05)	.053 (.024)	.24 (.23)	.65 (.15)
.012%	Dissolved	.22 (.02)	.028 (.009)	.07 (.07)	.37 (.04)
	Total (2)	.25 (.05)	.052 (.018)	.23 (.24)	.68 (.17)
	Dissolved	.22 (.01)	.024 (.009)	.04 (.09)	.36 (.06)
	Total (1)	.16 (.04)	.042 (.012)	.13 (.18)	.49 (.16)
.007%	Dissolved	.13 (.01)	.010 (.010)	.04 (.09)	.28 (.06)
	Total (2)	.16 (.03)	.031 (.018)	.11 (.16)	.48 (.16)
	Dissolved	.13 (.01)	.016 (.010)	.04 (.09)	.29 (.04)
	Total (1)	<.01	<.01	.01 (.04)	.18 (.09)
Control	Dissolved	<.01	<.01	<.01	.17 (.04)
	Total (2)	<.01	<.01	.01 (.04)	.16 (.10)
	Dissolved	<.01	<.01	<.01	.15 (.05)

[a] Numbers in parentheses indicate replicates.
[b] Numbers in parentheses represent standard deviations.

APPENDIX 2—Concentrations of Zinc, Copper, Aluminum, and Iron in Bioassay Aquaria During 60-day Bioassay on 1:12:18 Copper-to-Zinc-to-Aluminum Ratio Waste

	Concentration of waste	*Zn (mg/l)*	*Cu (mg/l)*	*Al (mg/l)*	*Fe (mg/l)*
	Total (1) [a]	1.58 (.43) [b]	.15 (.11)	2.30 (1.11)	4.39 (3.12)
.100%	Dissolved	1.25 (.23)	.042 (.018)	<.01	.82 (.52)
	Total (2)	1.56 (.46)	.13 (.06)	2.46 (1.09)	3.99 (2.37)
	Dissolved	1.21 (.17)	.043 (.021)	<.01	1.12 (.52)
	Total (1)	.93 (.22)	.074 (.04)	1.56 (1.01)	2.16 (1.41)
.056%	Dissolved	.69 (.09)	.012 (.007)	<.01	.30 (.14)
	Total (2)	.93 (.25)	.080 (.06)	1.43 (.88)	2.45 (1.55)
	Dissolved	.70 (.10)	.014 (.006)	<.01	.32 (.14)
	Total (1)	.53 (.16)	.034 (.03)	.81 (.38)	1.28 (.80)
.032%	Dissolved	.39 (.06)	<.01	.11 (.19)	.32 (.12)
	Total (2)	.58 (.13)	.042 (.03)	1.05 (.66)	1.88 (1.27)
	Dissolved	.39 (.06)	<.01	.18 (.15)	.32 (.12)
	Total (1)	.29 (.10)	.012 (.01)	.38 (.26)	.69 (.48)
.018%	Dissolved	.23 (.04)	<.01	.06 (.12)	.33 (.10)
	Total (2)	.29 (.11)	.014 (.01)	.38 (.29)	.78 (.43)
	Dissolved	.23 (.04)	<.01	.08 (.13)	.33 (.10)
	Total (1)	.18 (.07)	<.01	.20 (.21)	.51 (.32)
.010%	Dissolved	.14 (.02)	<.01	.04 (.07)	.29 (.08)
	Total (2)	.18 (.07)	<.01	.19 (.17)	.62 (.43)
	Dissolved	.14 (.02)	<.01	.03 (.06)	.27 (.08)
	Total (1)	<.01	<.01	.01 (.02)	.15 (.10)
Control	Dissolved	<.01	<.01	<.01	.14 (.04)
	Total (2)	<.01	<.01	.01 (.02)	.17 (.06)
	Dissolved	<.01	<.01	<.01	.12 (.08)

[a] Numbers in parentheses indicate replicates.
[b] Numbers in parentheses represent standard deviations.

APPENDIX 3—Concentrations of Zinc, Copper, Aluminum, and Iron in Bioassay Aquaria During 96-hr Bioassay on 1:4:6 Copper-to-Zinc-to-Aluminum Ratio Waste

Concentration of waste		*Zn (mg/l)*	*Cu (mg/l)*	*Al (mg/l)*	*Fe (mg/l)*
	Total (1) [a]	1.25 (.04) [b]	.30 (.03)	1.05 (.74)	2.36 (.12)
.067%	Dissolved	1.21 (.04)	.14 (.03)	<.01	.56 (.14)
	Total (2)	1.25 (.12)	.36 (.09)	89 (.63)	2.43 (.29)
	Dissolved	1.16 (.11)	.13 (.04)	<.01	.33 (.10)
	Total (1)	.86 (.20)	.19 (.04)	.79 (.14)	1.59 (.36)
.037%	Dissolved	.78 (.16)	.071 (.02)	<.01	.35 (.13)
	Total (2)	.83 (.18)	.19 (.04)	.74 (.21)	1.55 (.35)
	Dissolved	.73 (.11)	.063 (.02)	<.01	.24 (.11)
	Total (1)	.45 (.01)	.11 (.02)	.44 (.08)	1.05 (.13)
.021%	Dissolved	.39 (.01)	.052 (.01)	<.01	.45 (.07)
	Total (2)	.45 (.02)	.10 (.01)	.40 (.05)	.94 (.08)
	Dissolved	.38 (.02)	.053 (.00)	<.01	.42 (.03)
	Total (1)	.34 (.08)	.060 (.01)	.24 (.17)	.70 (.07)
.012%	Dissolved	.24 (.00)	.026 (.002)	<.01	.30 (.03)
	Total (2)	.32 (.06)	.063 (.01)	.10 (.14)	.63 (.06)
	Dissolved	.24 (.01)	.035 (.001)	<.01	.33 (.02)
	Total (1)	.27 (.12)	.041 (.011)	<.01	.59 (.06)
.007%	Dissolved	.14 (.01)	.012 (.008)	<.01	.27 (.03)
	Total (2)	.18 (.02)	.026 (.001)	<.01	.43 (.06)
	Dissolved	.14 (.00)	.012 (.008)	<.01	.27 (.05)
	Total (1)	<.01	<.01	<.01	.19 (.11)
Control	Dissolved	<.01	<.01	<.01	.11 (.04)
	Total (2)	<.01	<.01	<.01	.29 (.10)
	Dissolved	<.01	<.01	<.01	.11 (.03)

[a] Numbers in parentheses indicate replicates.
[b] Numbers in parentheses represent standard deviations.

APPENDIX 4—Concentrations of Zinc, Copper, Aluminum, and Iron in Bioassay Aquaria During 96-hr Bioassay on 1:12:18 Copper-to-Zinc-to-Aluminum Ratio Waste

Concentration of waste		Zn (mg/l)	Cu (mg/l)	Al (mg/l)	Fe (mg/l)
	Total (1)[a]	1.28 (.53)[b]	.11 (.03)	1.38 (.46)	2.45 (.58)
.100%	Dissolved	1.18 (.54)	.042 (.04)	<.01	.51 (.64)
	Total (2)	1.29 (.52)	.10 (.05)	1.21 (.72)	2.29 (.91)
	Dissolved	1.15 (.55)	.043 (.04)	<.01	.57 (.68)
	Total (1)	.76 (.31)	.057 (.031)	.73 (.36)	1.29 (.48)
.056%	Dissolved	.64 (.26)	.013 (.017)	<.01	.29 (.14)
	Total (2)	.75 (.31)	.057 (.031)	.53 (.41)	1.27 (.46)
	Dissolved	.69 (.31)	.021 (.015)	<.01	.29 (.15)
	Total (1)	.44 (.17)	.032 (.028)	.32 (.23)	.93 (.32)
.032%	Dissolved	.38 (.16)	.018 (.012)	<.01	.35 (.16)
	Total (2)	.56 (.25)	.039 (.023)	.37 (.28)	1.05 (.36)
	Dissolved	.38 (.16)	.015 (.012)	<.01	.32 (.17)
	Total (1)	.30 (.11)	.024 (.017)	.21 (.15)	.66 (.25)
.018%	Dissolved	.23 (.09)	.006 (.008)	<.01	.28 (.16)
	Total (2)	.43 (.25)	.021 (.015)	.21 (.15)	.55 (.17)
	Dissolved	.22 (.09)	.006 (.008)	<.01	.27 (.15)
	Total (1)	.25 (.13)	.012 (.008)	<.01	.35 (.11)
.010%	Dissolved	.15 (.06)	<.01	<.01	.22 (.09)
	Total (2)	.33 (.25)	.012 (.008)	<.01	.36 (.08)
	Dissolved	.15 (.06)	.006 (.008)	<.01	.19 (.10)
	Total (1)	<.01	<.01	<.01	.10 (.01)
Control	Dissolved	<.01	<.01	<.01	.09 (.02)
	Total (2)	<.01	<.01	<.01	.13 (.02)
	Dissolved	<.01	<.01	<.01	.08 (.02)

[a] Numbers in parentheses indicate replicates.
[b] Numbers in parentheses represent standard deviations.

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EGG DEPOSITION OF THE DESERT PUPFISH, *CYPRINODON MACULARIUS*, IN RELATION TO SEVERAL PHYSICAL PARAMETERS [1]

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The effects of spawning mop color, salinity, and water depth on the reproduction of the desert pupfish were examined. Green spawning mops were most frequently used for egg deposition. More eggs were deposited by fish acclimated to 5 0/00 salinity than those at 15 0/00. Fish acclimated to 5 0/00 used the deepest portion (37 cm) of their tank for egg deposition significantly more than other depths. Fish acclimated to 15 0/00 utilized the intermediate depth (22 cm) for egg deposition significantly more than other available depths.

INTRODUCTION

The California Department of Fish and Game's Water Pollution Control Laboratory has been evaluating many different fish species for consideration as standardized bioassay test species. Selection criteria were based upon the physical requirements of bioassays which often include wide ranges in temperature and salinity. These considerations limited the number of species which might be suitable for laboratory bioassays to eurythermal and euryhaline species, such as the desert pupfish, *Cyprinodon macularius* (Baird and Girard). Whichever species proved most feasible for laboratory bioassay testing would also have to be available in large quantities on a year-round basis. Since the pupfish appeared to meet the selection criteria, an efficient method to propagate large members of eggs and fry was needed.

Aspects of artificial propagation for this species have been extensively studied. Kinne (1960) and Crear and Haydock (1971) have described laboratory culture utilizing individual pairs of breeding adults. Miller (1948, 1950) studied cross breeding with related species. Barlow (1958, 1961), Cox (1966), Minckley and Arnold (1969), and Arnold (1972) have all described general behavior patterns and mating activities for this species. In all these studies egg production was limited because pairs of pupfish (one male and one female) were used in each tank. The present study examines reproduction in relation to color of spawning substrate, salinity, and water depth. Reproduction of groups of pupfish rather than pairs was examined.

MATERIALS AND METHODS

Fish Stocks

Fish used for our experiments were collected from canals around the Salton

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Sea, California during January 1975. The fish were transported in Salton Sea canal water (18 0/00 salinity) by airplane to Sacramento and then by truck to our laboratory. Formulated seawater of the same salinity was utilized at the laboratory. The fish were held in 1140-liter (300-gal) circular holding tanks containing a biological filter (Spotte 1970) to reduce build-up of waste products. Frozen brine shrimp were provided as forage during the holding and test periods.

By maintaining the fish at low densitites in each of the tanks and providing continuous water filtration to reduce ammonia levels, mortalities were kept to $< 1\%$. The fish were held in the laboratory for 2 months before the experiments were started.

Egg Collecting and Handling

Wool yarn was selected as the spawning substrate because it was available locally in a large choice of colors. Spawning maps were constructed of strands of colored wool yarn 38 cm (14.5 inches) long and consisted of 20 strands per mop. The strands were knotted as a group in the center and then slipped over a glass rod. The glass rod served not only as an anchor for the mop but also permitted retrieval of the mop and deposited eggs. Each mop was rinsed in fresh water for 24 hours before use to remove any soluble residues present on the yarn.

Mops were removed from the test tank each day and the eggs removed with tweezers, counted, and placed in a floating basket in a separate incubation tank. The basket was constructed of fiberglass window screen (Figure 1). The mesh size (approximately 1.0 mm) permitted the hatched fry to swim out of the basket into the hatching tank. This allowed easy separation of hatched fry from incubating eggs. The incubation tank water was maintained at 5 0/00 salinity and 20 $\pm$ 2 C (68 $\pm$ 3.6 F) based on results presented by Crear and Haydock (1971). Continual aeration provided water flow past the developing eggs. The incubator tanks had been filled and allowed to stand unused for several weeks prior to egg introduction. Algal growth developed in the unused tanks and provided food for developing fry. Dry, ground brine shrimp were fed as a supplement once per week.

The first series of experiments were designed to determine the preferred color of artificial spawning material. If *C. macularius* had a color preference, this could maximize spawning activity and egg deposition via visual stimulation. The second series of tests examined the relationship of depth and salinity upon egg deposition to determine if there was a preferred spawning depth at different salinities. The final experiment assessed the egg deposition rate of adult *C. macularius* held under defined laboratory conditions. For each test a new group of 10 females and 2 males was used. This ratio was maintained throughout the study and mortalities were replaced. Chi square tests were used to determine statistical significances of egg deposition rates established during the various experiments.

These experiments are designed to provide further understanding of environmental influences on the reproductive biology of *C. macularius.* This would not only evaluate the most efficient method to rear this species for the laboratory bioassay testing program, but these same methods could also find application for related pupfish species to supplement declining populations.

FIGURE 1. Floating incubation basket

Color Preference

Ten female and two adult male pupfish were placed in a 95-liter (25-gal) substrate filtered aquaria. Salinity was 5 0/00 and temperature 20 ± 2 C (68 ± 3 F). Two mops of different colors (green, gold, grey, or beige) were placed in the tank at different locations. Each day the mops were removed, the eggs collected, and the mops returned to the test tank at reversed locations. A heat-light stimulus approximating summer conditions was applied to the tank to initiate egg deposition. This consisted of 14-hour light cycle and slow elevation of tank temperature from 20 C up to 28 C (82 F). At the end of the light period, the heater and light were slowly turned off to simulate sunset. The water cooled

to 20 C by the start of the next cycle. At the end of each week the total number of eggs per color was determined, and the mop color with the highest egg deposition was utilized again the following week against either a new color or a repetition of the previous week's color.

Salinity and Water Depth

Techniques similar to those presented above were utilized with the following modifications. Two 226-liter (70-gal) tanks equipped with a biological filter (Spotte 1970) were used for this experiment. Concrete blocks stacked at one end, created different spawning depths. The eggs appeared to adhere to the spawning wool, but as a precaution, the arrangement of the blocks prevented eggs deposited on a higher level from drifting down to a lower level. Green spawning mops were placed at each of the three depths measured from the surface (2 to 6, 18 to 22, and 33 to 37 cm) (0.8 to 2.4, 7.1 to 8.7, and 13 to 14.6 inches). One tank was maintained at 5 0/00 and the other at 15 0/00 salinity throughout the study. These salinities were selected based on previous results of Kinne (1960).

Egg Production

The experimental design used for salinity and water depth was modified as follows: The water in both tanks was maintained at 5 0/00 salinity and the daily range in temperature was reduced to 15 to 24 C (59–75 F) to simulate the fall conditions present in the Salton Sea Canals. Mops were placed on the bottom of the tanks and checked every other day. A new group of 10 female and 2 male pupfish were used for this experiment.

RESULTS AND DISCUSSION

The order of increasing egg deposition/mop color was grey, beige, gold, green (Table 1). Preference for green spawning substrate is not unexpected since plants are customarily used by this species for egg deposition. Random choices would result in similar numbers of eggs being deposited on each color. Perhaps the particular wave lengths of light which cause green coloration (490–575 mμ) act as a visual stimulus to the pupfish. The variability in the number of eggs deposited during any particular week was probably related to the number of females actively spawning. Crear and Haydock (1971) reported large variations in not only the fecundity of individual female pupfish, but also the frequency of spawning.

TABLE 1. Spawning Mop Color Preference of Desert Pupfish, *Cyprinodon macularius*

Week	*Color choice*	*Total eggs deposited*
1	green/gold	56/24
2	green/grey	37/18
3	green/grey	43/22
4	green/beige	117/75
5	green/gold	41/15
6	green/gold	161/71
7	green/grey	61/20

The second experiment demonstrated increased egg deposition at almost all depths in lower salinities (Table 2). The distribution of eggs at each depth differed significantly from the expected distribution of 33:33:33 for each treat-

ment group (5 0/00 and 15 0/00) ($X^2 = 772.6$, $P = 0.01$, d.f. = 2, and $X^2 = 619.4$, $P = 0.01$, d.f. = 2, respectively). Results indicate pupfish preferred the 33–37 cm level for egg deposition at 5 0/00 and the 18–22 cm level at 15 0/00.

TABLE 2. Effects of Depth and Salinity on Egg Deposition of the Desert Pupfish, *Cyprinodon macularius*

		Salinity	
Week	*Depth* *	*5 0/00*	*15 0/00*
1	A	364	73
	B	221	56
	C	537	53
2	A	155	66
	B	316	478
	C	823	153
3	A	14	152
	B	707	425
	C	739	127
4	A	294	57
	B	179	143
	C	256	26
Subtotal	A	827	348
	B	1423	1102
	C	2355	359
Totals		4605	1809

* A = 2–6 cm
B = 18–22 cm
C = 33–37 cm

This difference in spawning rates at different salinities is unknown but may be related to energy requirements. Rao (1968) evaluated the energy expenditure for osmoregulation at different salinities. He demonstrated increased expenditure with increasing salinity. If a female pupfish had to shift more of her available energy stores to osmoregulatory processes, less energy would be put into egg production. This could account for the overall reduced egg production at 15 0/00 compared to the production at 5 0/00.

The final study recorded egg production of replicate groups of pupfish held at low salinities (5 0/00) utilizing green spawning mops placed at 33 to 37 cm (13 to 14.6 inches). Egg production during the 31-day test period yielded an average of 1554 eggs/week. Crear and Haydock (1971) reported that female pupfish spawned 50 to 200 eggs once per week. The present study shows a similar level of production. However, the female pupfish in the present study survived for a longer time period (4 to 6 months) than the 2 months reported by Crear and Haydock (1971). The methods reported here increase the survival of spawning female pupfish and provide an efficient method for egg propagation. The hatching system described permitted fry survival and growth. Approximately 70% of the eggs hatched and 50% of the resulting fry lived for a period of 3 months. Longevity of the fry could not be determined because testing was terminated. The fry were used for standardized bioassay testing.

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NOTES

NOTES ON THE LIFE HISTORY OF THE CALIFORNIA CLINGFISH, *GOBIESOX RHESSODON* (GOBIESOCIFORMES, GOBIESOCIDAE)

INTRODUCTION

The California clingfish, *Gobiesox rhessodon* Smith, 1881, ranges from San Bartolome Bay, Baja California, to Pismo Beach, California (Miller and Lea 1972). Throughout its range this species is secretive and relatively scarce. Consequently, virtually nothing is known of its life history. The collection of 103 California clingfish during studies on wooly sculpin, *Clinocottus analis*, by Wells (1974) and on rockpool blenny, *Hypsoblennius gilberti*, by Dayneko (1975) in southern California presented an opportunity to investigate some aspects of the life history of *G. rhessodon.*

METHODS

The study was conducted 1.5 km (approximately 1 mile) northwest of Point Fermin, Los Angeles Co., California (lat 33°42′ N, long 118°17′ W), from May 1971 to September 1972. California clingfish were collected using 10% quinaldine solution in ethyl alcohol. Upon capture, they were placed in plastic bags and frozen. Later the fish were thawed and weighed to the nearest decigram and the gonads to the nearest milligram. Standard length (SL), total length (TL), and sex were recorded. Number of ova per female was determined by direct count. Both frequency occurrence and number of individual prey items were recorded from the stomachs.

DISTRIBUTION AND ASSOCIATIONS

California clingfish were most frequently found under small, flat, smooth rocks in the shallow peripheries of tidepools from 0.3 m (1 ft) above Mean Lower Low Water (MLLW) to the lowest pool collected at 0.5 m (1.7 ft) below MLLW. Peak densities, between 0.3 and 0.5 fish/m^2 of pool surface, occurred between 0.15 m (0.5 ft) above MLLW and 0.3 m (1 ft) below MLLW. The average population density throughout the intertidal region where these fish occurred was 0.17 fish/m^2.

Fishes associated with the California clingfish were wooly sculpin; rockpool blenny; young opaleye, *Girella nigricans*; spotted kelpfish, *Gibbonsia elegans*; striped kelpfish, *Gibbonsia metzi*; and dwarf surfperch, *Micrometrus minimus.*

DIET

The major food items (over 50% occurrence) were gammaridean amphipods and isopods (Table 1). Several other arthropods, polychaetes, mollusks, and echinoderm tube feet were ingested much less frequently. No seasonal change in diet was noted.

TABLE 1. Diet by Frequency Occurrence, Percentage Occurrence, and Number of Organisms of 73 California Clingfish (24 to 49 mm SL).

Item	*Frequency*	*Percent*	*Number*
Annelida			
Phragmatopoma californica	4	5.5	4
Mollusca			
Gastropoda (unidentified)	3	4.1	4
Littorina planaxis	2	2.7	3
Arthropoda			
Crustacea (unidentified)	1	1.4	1
Ostracoda	1	1.4	1
Malacostraca			
Tanaidacea			
Anatanais normani	4	5.5	5
Isopoda			
Cirolana harfordi	37	50.7	92
Exosphaeroma sp.	2	2.7	2
Amphipoda			
Gammaridea	41	56.2	63
Caprellidea			
Caprella sp.	1	1.4	1
Echinodermata			
Strongylocentrotus sp. tube feet	1	1.4	6
Algae	1	1.4	–
Unidentified (fragments)	12	16.4	12
Empty	10	13.7	–

REPRODUCTION

Monthly changes in the gonosomatic index [GSI = (gonad weight/body weight $\times$100] indicate spawning takes place approximately from late September to October. However, spawning activities may begin as early as July or August (Figure 1). Females appear to be sexually mature at about 25 mm SL. The number of mature ova per female ranges from 145 to 385 ($\bar{X}$ = 261) and appears to increase irregularly with an increase in standard length (Figure 2).

Intertidal California clingfish population densities appeared to decrease from August through November. This decrease may be associated with offshore movements related to spawning behavior or possibly post-spawning mortality.

AGE AND GROWTH

Length-frequency distributions based on 2-month intervals were prepared from 101 specimens (Figure 3). Two immature specimens, one 17 mm SL taken in December and one 24 mm SL collected in May, were not included. Sexes were separated because of a marked difference in size. All but one of the 24 fish over 40 mm SL were male. Three or four length-frequency modes are apparent in the females. The six small, nearly spherical otoliths examined are in general agreement with these modes and indicate at least five age classes. Shifts in male length-frequency modes are not as discernible but six otoliths examined seem to indicate at least five age classes.

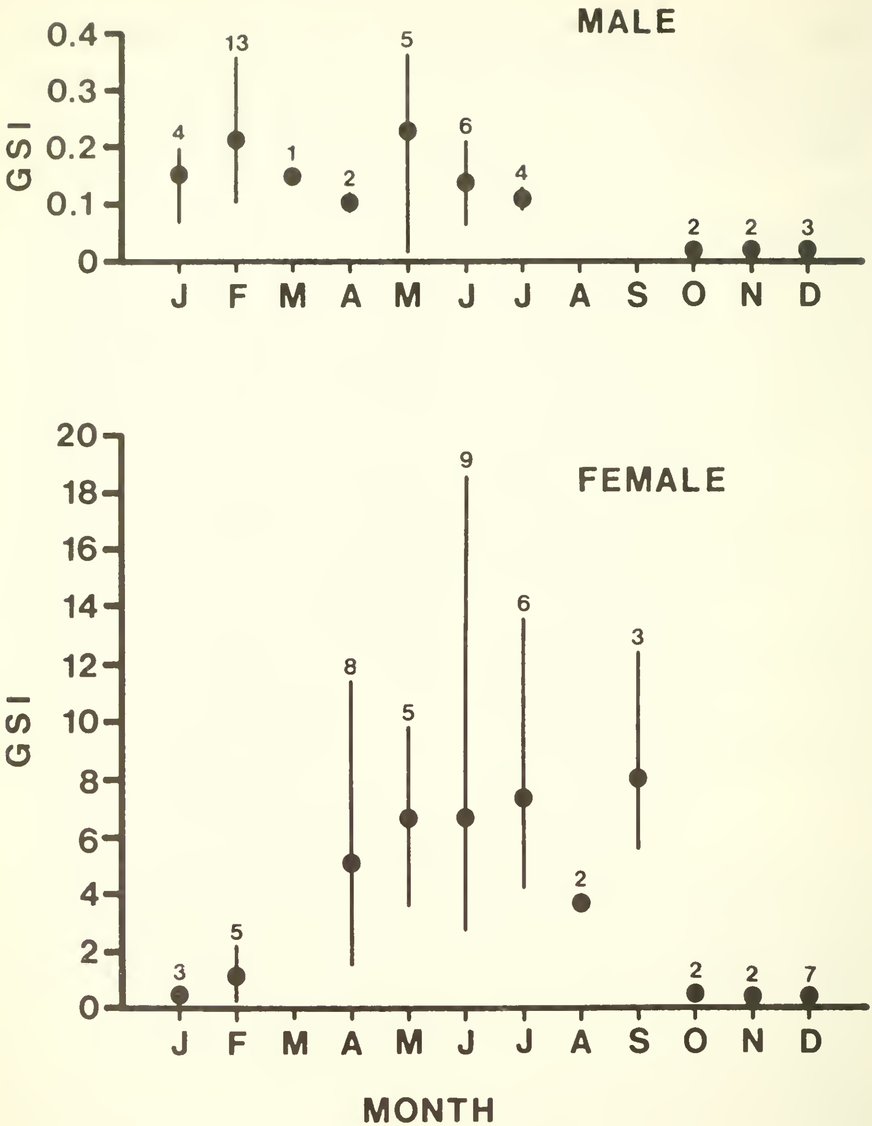

FIGURE 1. Monthly variation in the gonosomatic index (GSI) for male and female California clingfish. Mean, range, and sample size are indicated.

WEIGHT-LENGTH RELATIONSHIPS

The relationship between standard length and weight can be described by the equation: $W = 0.000030\ L^{2.94}$ ($r = 0.98$; $N = 65$) where W is weight in grams and L is standard length in millimeters. Ripe females were omitted from the relationship because of the great contribution of the ovaries to total weight.

The relationship between total length and standard length can be described as $TL = 1.15\ SL + 1.81$ ($r = 0.99$; $N = 91$).

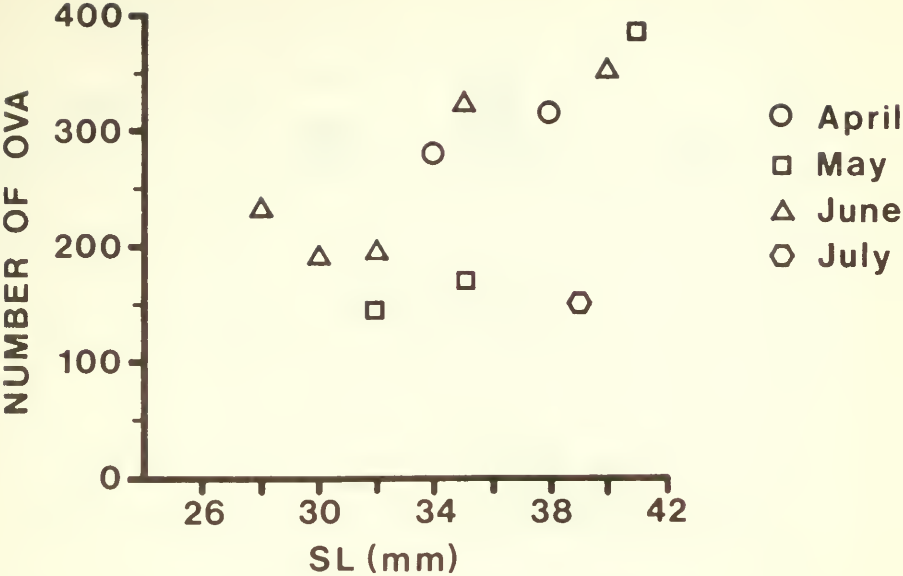

FIGURE 2. Relationship of standard length (SL) to number of mature ova in California clingfish.

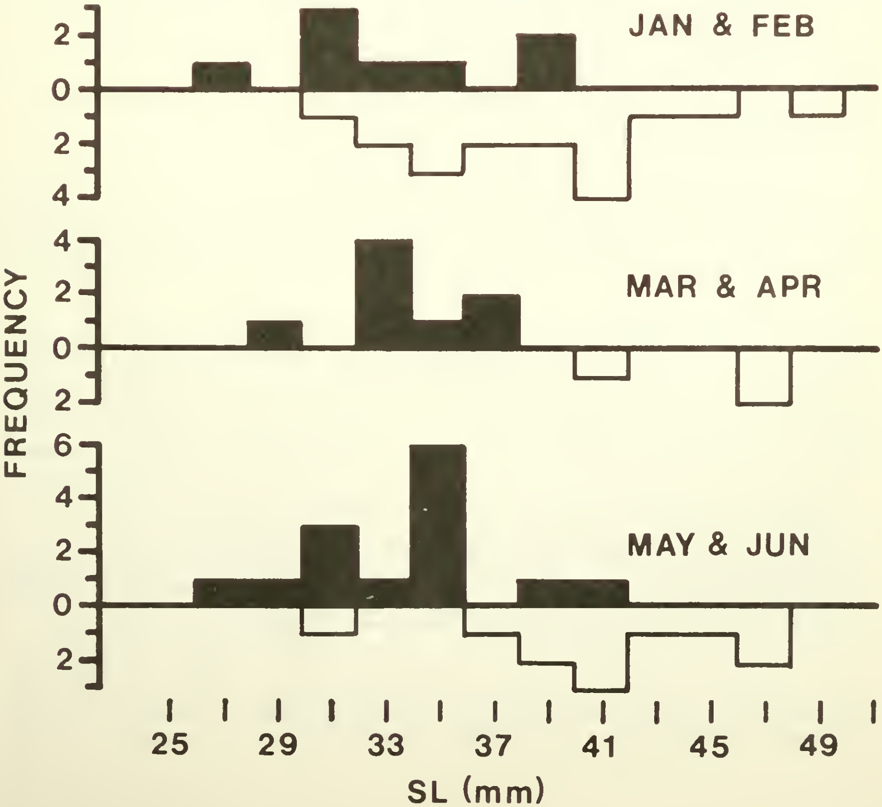

FIGURE 3. Length-frequency distributions for female (solid) and male (open) California clingfish.

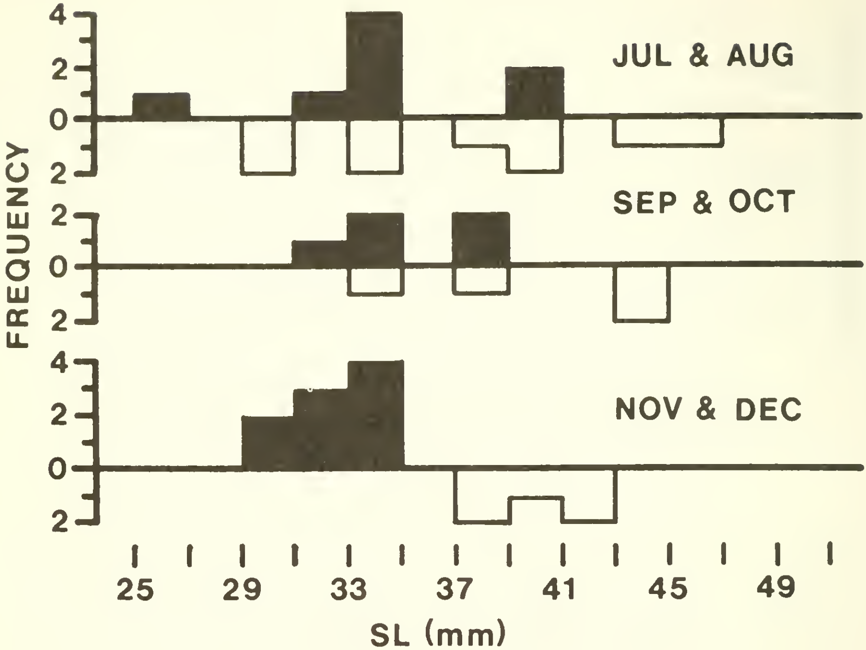

FIGURE 3. Continued

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AGE STRUCTURE OF A TIDEPOOL SCULPIN, *OLIGOCOTTUS MACULOSUS,* POPULATION IN NORTHERN CALIFORNIA

The tidepool sculpin, *Oligocottus maculosus,* is a common intertidal cottid and the dominant intertidal fish species from central California northward along the Pacific coasts of the United States and Canada. The homing behavior (Gersbacher and Denison 1930; Green 1971*b*) and movement and distributional patterns (Morris 1960, 1961; Greene 1971*a*, 1971*b*, 1971*c*; Nakamura 1976*a*, 1976*b*) of the species have been reported on previously. Atkinson (1939) and Green (1971*c*) indirectly profiled the age structure of *O. maculosus* populations in Puget Sound and the Gulf of Alaska, and southwestern Vancouver Island, respectively, by graphing lengths of collected fish and denoting peaks in frequency distributions. Chadwick (1976) aged vertebrae from *O. maculosus* populations at a site on southwestern Vancouver Island and another along northern California. However, the relatively limited samples (78 at Port Renfrew, British Columbia, and 31 at Bruels Point, California) were collected only during a 1-week period in July 1973.

O. maculosus population studies were conducted in Trinidad Bay, California, from 1965 to 1970 (Moring 1972, 1976). The area is on the southern portion of the range distribution of *O. maculosus.* Age structure profiles were used in conjunction with population estimates to compare with populations of more northern waters (Atkinson 1939; Green 1971*c*; Chadwick 1976).

Trinidad Bay is located approximately 23 km (14 miles) north of Humboldt Bay, on the northern California coast, and is characterized by rocky shores and scattered tidepools. Between May 1965 and May 1970, 1,072 *O. maculosus* were examined and measured during sampling trips. Fish were collected with a variety of hand nets and seines and anesthetized with quinaldine prior to handling and measuring. Fish ranged from the minimum size taken by sampling methods of 10 mm (0.4 inches) to 95 mm (3.8 inches) total length (TL), and averaged 46.7 mm (1.8 inches) TL.

It is apparent that two age classes (0- and 1-year) dominate the population in Trinidad Bay, and that members of at least one older year class are present (Figure 1). Young of the year *O. maculosus* begin to appear in collections in April. By August, there is a distinct bi-modal appearance to the size composition. In September, the 0-year class becomes the dominant group. From collections made in 1969, I estimated that 50.0% of the *O. maculosus* examined in August were 0-year fish, and 45.5% were 1-year fish. The remaining 4.5% were 2-year or older fish.

Linear growth patterns effectively cease in all year classes after October. Size increases are not noted until the following May. This pattern is similar to that found by Green (1971*c*) for southwestern Vancouver Island populations.

Growth rates in Trinidad Bay were similar to those found by Atkinson (1939) in Puget Sound and Alaska, and Green (1971*c*) along Vancouver Island. From June through August, Trinidad Bay mean year class sizes for 0- and 1-year fish were larger than those in more northern locales, but these differences averaged less than 5 mm. By December, mean age class sizes in Trinidad Bay were virtually the same as their counterparts off Vancouver Island (Green 1971*c*).

Using vertebral aging, Chadwick (1976) found no growth differences between Bruels Point and Vancouver Island populations.

Surface water temperatures in Trinidad Bay remain characteristically cool throughout the year, averaging 10.1 C (50.2 F) in spring and 11.9 C (53.4 F) in summer (Allen 1964). Temperatures in tidepools ranged from 10.0 to 16.7 C (50.0 to 62.1 F) in summer (average 12.6 C or 54.7 F) and 8.3 to 17.2 C (46.9 to 63.0 F) during the remainder of the year (average 12.2 C or 54.0 F). Summer temperatures were not significantly cooler in Vancouver Island pools studied by Green (1971*c*). Therefore, warmer water temperatures do not appear to account for the slightly increased growth rates of Trinidad Bay populations during summer months.

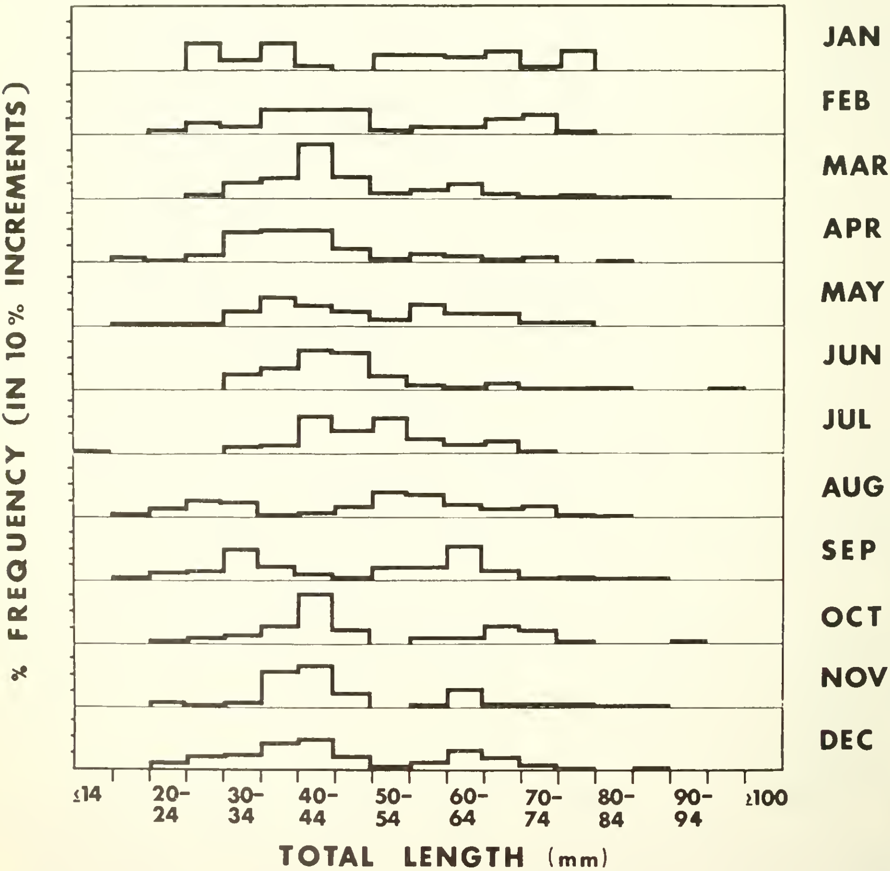

FIGURE 1. Pooled length frequency distribution, by month, of *Oligocottus maculosus* captured and measured in Trinidad Bay, California.

Both Atkinson (1939) and Green (1971*c*) indicate *O. maculosus* populations are primarily of the 0- and 1-year age classes, with some older representatives present throughout the year in northern populations. Although Atkinson could not separate 1- and 2-year fish in his Puget Sound collections, he could make

this distinction for Alaskan populations. Chadwick (1976) has indicated there may be as many as six *O. maculosus* age groups present in populations he studied. However, his collections, made in July, showed no 0-year fish present, based on vertebral aging; and he indicated two age classes dominated, as Atkinson (1939), Green (1971*c*), and this work have shown. The Trinidad Bay populations, which approach the southern range limit of the species, clearly have representatives of the 2-year-age group and possibly members of the 3-year group as well, but the proportion of these age groups in the population is quite low.

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A SIMPLE METHOD FOR TAGGING FISH UNDERWATER

INTRODUCTION

An understanding of the movements of fishes is essential to any effective research on, or management of, their populations. However, many fish species are badly damaged by conventional capture and tagging methods and thus have a high mortality rate when returned to the water. The need therefore exists for a method whereby fish can be tagged without capture or removal from their

natural environment, thus minimizing the stress that they experience.

Such a method has been developed for large pelagic fishes. Mather (1963) and Blunt and Messersmith (1960) used a "dart tag" during the mid 1950's which consisted of a plastic streamer attached to a stainless steel dart. This tag was used for tunas as well as other species, where the fish were caught by hook and line and maneuvered alongside the boat, harpooned with the tag and then released by cutting the leader close to the hook.

Since this tag was developed it has had wide usage by several investigators, including Yamashita and Waldron (1958) who used an all plastic version to mark yellowfin tuna, *Neothunnus macropterus,* and skipjack tuna, *Katsuwonus pelanis.* Their method, however, involved removing the fish from the water during tagging.

The underwater technique outlined here achieves the objective of tagging fish without excessive disturbance, but with the loss of length and weight measurements. A somewhat similar method, with the same limitations, was described by Ebert (1964), but his method was more complex and had a tagging range of less than 25 cm (10 inches). Our much simpler method has a tagging range well in excess of 1 m (3 ft). The only recorded use of the method described in this paper was by Cousteau and Cousteau (1970) to tag sharks in the Red Sea.

The tagging method described herein is currently used to study several rocky-reef fish species in southeastern Australian waters, including the red morwong, *Cheilodactylus fuscus* (Figure 1). The technique should be equally applicable to fish from other reef areas, including California.

FIGURE 1. Red morwong, *Cheilodactylus fuscus,* tagged with Floy FT-1 type dart tag with a long plastic streamer. *Photograph by J. Matthews, September 1976.*

CONSTRUCTION OF TAGGING HEAD

This method of tagging utilizes a numbered, plastic, single-barbed dart tag (FT-1, manufactured by Floy Tag and Mfg. Inc., 4616 Union Bay Pl. N.E., Seattle, Washington 98105). Our method differs from the surface tagging method employed by Mather (1963) in that tagging is carried out underwater by either a free or scuba diver, and differs from Ebert's (1964) underwater tagging method in that the tagging needle is mounted in a brass head screwed to the end of a standard handspear (Figure 2A).

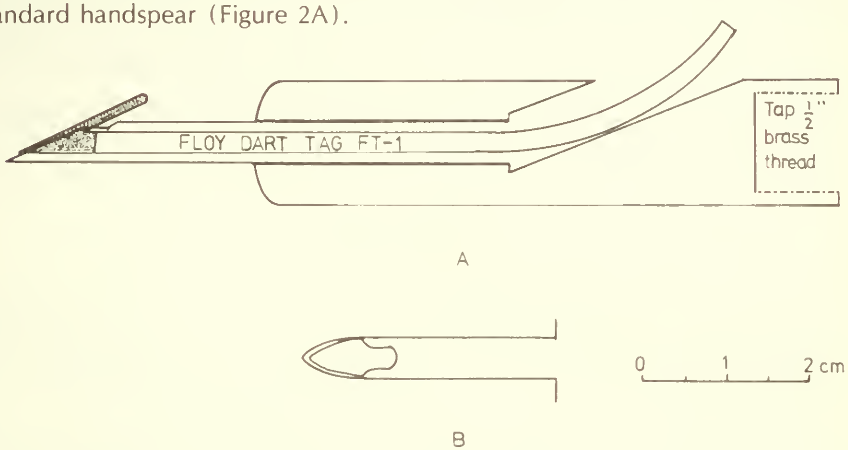

FIGURE 2. Dimensions of tagging head and needle. A. Sectional view of tagging head complete with tag; B. Plane view of needle tip.

The needle is constructed of 6 cm (2.4 inches) of stainless steel tubing 3 mm (0.1 inch) I.D. and 5 mm (0.2 inch) O.D. machined to a 25° angle at one end. The back of the angle is blunted and deepened (Figure 2B) so that the tag barb is housed neatly and not cut off as the needle penetrates the fish. A piece of solid, hexagonal brass rod, 1.5 cm (0.6 inch) in diameter and 7 cm (2.8 inches) in length, is internally threaded with a 13 mm (0.5 inch) thread so as to screw onto a standard handspear. A hole, 5 mm (0.2 inch) in diameter and 3 cm (1.2 inches) long is drilled in the center of the other end to house the needle. The needle is either "heat-sweated" or silver soldered into the brass rod. A second hole, 7 mm (0.3 inch) in diameter, is drilled diagonally into the side of the brass rod, starting 4 cm (1.6 inches) from the needle end of the rod until the center hole is met.

It is important that the construction of the head allows the tag to fit loosely within the needle, otherwise the tag may be partially or completely retracted from the fish when the applicator is withdrawn. The fit should not be so loose that the tag falls out while swimming with the spear.

TAGGING PROCEDURE

Fish are tagged by shooting them with the handspear so that the needle penetrates the skin and deposits the tag within the musculature. The tag should be placed above the lateral line and below the anterior section of the dorsal fin, preferably so that the barb will hook behind the interneural bones. Fish should also be tagged at an oblique angle from behind so that the tag will lie nearly flush

with the body surface and thus offer minimal water resistance (Figure 1).

By altering the size of the needle and tag and by using a differential amount of force when placing the tag, fishes of a wide variety and size range (e.g. scorpaenids, serranids, carangids, labrids, and acanthurids) may be marked by this method.

A number of dart tag sizes are available. The one described (Floy FT-1) is suited to a fairly large size range of fishes, e.g. $\sim$ 1–50 kg ($\sim$ 2 to 100 lb), but for the larger fish within this range the tag should have a longer plastic streamer. For smaller fish the FT-2 tag used by Ebert (1964) with the dimensions of the tagging needle modified accordingly, would be more suitable.

This system requires the diver to carry a small underwater slate and pencil so that relevant information can be recorded. If only one species is to be tagged, a list of tag numbers can be prepared prior to use and locality data filled in after tagging is completed.

DISCUSSION

Topp (1963) showed that a variety of Florida reef fishes exhibited relatively high percentage returns after tagging when compared with tag returns from fishes marked in other habitats. The tendency for a number of such reef-associated fish species to be readily recaptured is documented and advantage can be taken of this characteristic to obtain biological information on them.

The technique described here enables the successful tagging of those fish species that can normally be approached while diving. It eliminates the need to catch the fish and does not necessitate their removal from the water. Fish tagged in this way have been observed to resume normal behaviour very shortly after tagging, indicating that they have suffered little stress. One red morwong marked by this method was observed in good condition 11 months after tagging and had travelled a distance of approximately 5.5 km (3.5 miles) from the area of tagging.

This method also incorporates the desirable features of the conventional dart tag method of marking, including rapid application, little resistance by the tag to the flow of water, minimal interference with the fish's normal activity, and high visibility.

It should be noted that this method need not be restricted to reef-dwelling species and can be applied to some pelagic fishes (e.g. carangids); however, it may be necessary to mount the tagging needle on a speargun to mark larger pelagic species effectively.

An obvious shortcoming of this method is the sacrifice of accurate length and weight measurements at the time of tagging. However, estimates of these can be made as is usually done in dart-tagging large pelagic fishes. Other disadvantages of this method are that the efficiency of tagging is dependent on the accurate placement of tags, otherwise fish mortality and tag loss will be greater, and the tagging needle can be easily damaged by impact against the substrate if it is used negligently.

ACKNOWLEDGMENTS

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THE HALFMOON, *MEDIALUNA CALIFORNIENSIS*, AS A CLEANER FISH

Cleaning symbiosis involves an animal feeding upon ectoparasites or other deleterious materials it has removed from the body of another animal (Limbaugh 1961; Feder 1966). Although it cleans other fishes infrequently, the señorita, *Oxyjulis californica*, is by far the predominant cleaner among California inshore marine fishes (Limbaugh 1955, 1961; Hobson 1971; Bray and Ebeling 1975). Other California species have been observed cleaning also, although less frequently: the kelp surfperch, *Brachyistius frenatus* (Limbaugh 1955, 1961; Hobson 1971; Bray and Ebeling 1975); the sharpnose surfperch, *Phanerodon atripes* (Gotshall 1967; Hobson 1971); the black surfperch, *Embiotoca jacksoni*, and pile surfperch, *Damalichthys vacca* (Limbaugh 1955); the rainbow surfperch, *Hypsurus caryi* (Gotshall 1967); the white surfperch, *Phanerodon furcatus* (Hobson 1971); the blacksmith, *Chromis punctipinnis* (Turner, Ebert, and Given 1969); and the rock wrasse, *Halichoeres semicinctus* (Hobson 1976). With the following account, another species is now added to this list: the halfmoon, *Medialuna californiensis*, of the percoid family Scorpididae.

I have observed halfmoon cleaning other fishes on two occasions. The first instance occurred on 14 February 1977. I was scuba diving in 9 m (30 ft) of water at Naples Reef, located about 1.6 km (1 mile) offshore near Santa Barbara. Diving conditions were excellent, with water visibility exceeding 15 m (50 ft) and water temperature 16 C (61 F). At noon, I came upon a pair of common molas, *Mola mola*, each approximately 50 cm (20 inches) long, hovering upright about 1 m (3 ft) apart in midwater. This species is a common host to other cleaners, yet these individuals were being circled closely and actively by four adult halfmoon, each approximately 25 cm (10 inches) long. As I approached, I could see clearly the halfmoon frequently picking at the flanks of the molas. Occasionally, a mola would lift one of its pectoral fins, and a halfmoon would immediately approach and pick at the area which had been covered by the fin. There appeared, however, to be no communicative signals occurring between the fishes as reported by Losey (1971). I observed this behavior for several minutes before resuming other activities, and upon returning to the same location about 15 min later, found no trace of either species.

The second incident was very similar to the first, and occurred at Fry's Harbor,

Santa Cruz Island, on 2 December 1977. Water conditions were nearly identical to those of the previous occasion, visibility was 50 ft and temperature 17 C (63 F). At 1500 hr, my partner and I spotted a mola, approximately 75 cm (30 inches) long, hovering in midwater. Three adult halfmoon, each approximately 25 cm (10 inches) long, were closely circling the mola and picking at its flanks. Characteristic of many cleaner hosts, the mola would occasionally assume head-up posture for several seconds during particularly intense cleaning bouts by the halfmoon.

Although the kelp-bed fish communities at Naples Reef and Santa Cruz Island have been studied continuously and intensively by University of California research divers since the early 1970's, no reports of halfmoon cleaning behavior at these sites have been made. Moreover, since the halfmoon has never before been documented as a cleaner fish, such behavior probably occurs very rarely throughout the range of this species. While the halfmoon possesses a small mouth, which facilitates picking small individual prey such as most ectoparasites (Hobson 1971), this species normally consumes animal-encrusted algae in its kelp-bed habitat (Limbaugh 1955; Quast 1968). Hobson (1971) suggested that such incidental cleaners treat their hosts as simply another food substrate. Indeed, the growing number of California fishes which have been observed cleaning indicates that, under proper circumstances, individuals of nearly any species with the appropriate feeding morphology occasionally will clean another fish.

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RECORDS OF *CANCER OREGONENSIS* IN CALIFORNIA (BRACHYURA: CANCRIDAE)

Cancer oregonensis (Dana 1852) is one of the smallest members of the family Cancridae in California. Carlton and Kuris (1975) stated that it is rare south of

Oregon, while Ricketts, Calvin, and Hedgpeth (1969) said that it is rare south of Washington. Rathbun (1930), MacKay (1943), and Nations (1975) gave the southern limit of the species as Santa Barbara; Word (1975) gave the limit as "off Palos Verdes", Holmes (1900) and Schmitt (1921) recorded it from "Lower California", and Ricketts, et al. (1969) stated that it reached Baja California.

Collecting by scuba diving from the SEARCHER off Del Norte, Humboldt, and Mendocino counties in 1971 provided a good series of specimens of this species for the Allan Hancock Foundation. I examined records of these and other specimens at the Allan Hancock Foundation, the California Academy of Sciences, in my private collection, and in the literature (Table 1).

TABLE 1. Records of *Cancer oregonensis* in California.

Latitude (degrees north)	*Locality*	*Depth*	*Date*	*Collector*
	Del Norte County:			
41°45′	St. George's Reef	11–14 m	2 Aug. 1971	*Searcher* sta. 164
41°45′ N	Castle Rock	8 m	3 Aug. 1971	*Searcher* sta. 165
41°40′ N	Damnation Creek	shore	9 March 1968	M.K. Wicksten
	Humboldt County:			
41°35′	Redding Rock	11 m	30 July 1971	*Searcher* sta. 161
41°05′	Prisoner's Rock	9–11 m	31 July 1971	*Searcher* sta. 162
41°05′	Trinidad Harbor	2–4 m	1 Aug. 1971	*Searcher* sta. 163
41°05′	Trinidad Harbor	shore	6 Feb. 1971	M.K. Wicksten
40°45′	Humboldt Bay	n.r.[1]	18 June 1916	Scripps Inst. Ocn. (Rathbun 1930)
40°15′	Punta Gorda	shore	23 Oct. 1966	M.K. Wicksten
40°00′	Point Delgada	n.r.[1]	29 July 1971	*Searcher* sta. 158
	Mendocino County:			
40°00′	Tolo Bank	22–31 m	28 July 1971	*Searcher* sta. 156
39°25′	So. Shore Noyo River	shore	9 Aug. 1971	*Searcher* sta. 204
38°55′	Point Arena	shore	1949	Emerson and Barnard
38°55′	Point Arena	shore, subtidal	n.r.	D. Gotshall (pers. commun.)
38°55′	Anchor Cove	n.r.[1]	n.r.	Tom Burch
37°50′	Farallon Islands	50 m	22 March 1890	*Albatross* sta. 3159 (Rathbun 1930)
37°50′	Farallon Islands	67 m	24 Sept. 1961	*Velero IV* sta. 7422
34°25′	Santa Barbara	n.r.[1]	1880	D.S. Jordan (Rathbun 1930)
33°40′	off Palos Verdes	23 m	1975	S. Carlin

[1] n.r.: not recorded

The records show that this species is most common north of Point Arena. This area contains boreal water corresponding to the range 4.8 to 11.3 C (40.7 to 52.3 F) given for the species by Nations (1975). Specimens taken south of Point Arena occurred in deeper water, which would be predicted if the species were confined to such a range of temperatures.

The southern limit of the range of *C. oregonensis* remains uncertain. The record given by Word (1975) is the most definitive southern locality because neither Holmes (1900) nor Ricketts, et al. (1969) gave exact localities for the species in Baja California. So few specimens have been taken in southern California that it is impossible to say whether the species is a rare resident, or whether only occasional strays settle there during very cold years.

ACKNOWLEDGMENTS

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COLORADO SNAPPER, *LUTJANUS COLORADO,* TAKEN NEAR MORRO BAY ADDS NEW FAMILY (LUTJANIDAE) TO CALIFORNIA'S MARINE FISH FAUNA

On 22 October 1976, a mature female Colorado snapper, *Lutjanus colorado* Jordan and Gilbert (Figure 1), was taken by a trammel net fisherman in approximately 4 fm (7m) of water off Villa Creek in Estero Bay, San Luis Obispo County, California. After 5 days on ice and under refrigeration, the fish measured 665 mm (26.2 inches) SL, 840 mm (33.1 inches) TL and weighed 7.5 kg (16.5 lb). Otoliths and scales showed eight winter rings with summer growth at the margins.

Colorado snappers generally have been found from Guaymas, Mexico, to Panama. Berdegué (1956) referred to *L. colorado* as "Pargo Colorado" and stated that they were abundant from Guaymas to Mazatlan. Walford (1937) gave their range as "from Pt. Arena (Gulf of California) through the Gulf of California and along the Mexican coast to Panama." Meek and Hildebrand (1925) gave "Guyamas [sic] south to Panama" and noted that their specimens were from "Chame Point, Balboa, and Corozal." Fitch (1952) reported three Colorado snappers from among four species (15 specimens) of *Lutjanus* taken from Santa Maria Lagoon, Baja California, Mexico, in April 1950, thus establishing their presence on the outer coast of Baja California. The Estero Bay fish represents a northern range extension for *L. colorado* of approximately 780 nautical miles (1445 km).

FIGURE 1. *Lutjanus colorado* taken in Estero Bay, San Luis Obispo County, California, October 22, 1976. *Photograph by Jack W. Schott.*

Berdegué (1956) reported that Colorado snappers attain a length of (about) 80 cm (31.5 inches). Meek and Hildebrand (1925) gave a maximum length (they did not say whether it was SL or TL) of 435 mm (17.1 inches) for the specimens they examined. Walford (1937) stated that "The largest specimen taken on the 1935 cruise of the *Haida* measured 30 inches," but the caption with a photograph of *L. colorado* (plate 57b) reads "36 inches." Hiyama (1937) gave "2 feet" as maximum size. The evenly rounded figures of Berdegué, Walford, and Hiyama suggest estimates rather than actual measurements. Because of this and the fact that none of the above authors reported weights, the Estero Bay specimen is offered as both a size and weight record for *L. colorado,* until a larger specimen is confirmed.

A veteran Morro Bay fisherman reported that he had seen "200 to 400 pounds of red snappers" taken several times in the mid-1930's between Anacapa Island and Santa Barbara (Bill Wilson, pers. commun.). Water temperatures were relatively warm from 1936 to 1939 (Radovich 1961), and several southern species were reported from off southern and central California. Those reported in *California Fish and Game* were jumbo squid, *Dosidicus gigas* (Clark and Phillips 1936; Croker 1937*b*); frigate mackerel, *Auxis thazard* (Godsil 1936); pilotfish, *Naucrates ductor* (Croker 1936); salema, *Xenistius californiensis* (Phillips 1936); Monterey Spanish mackerel, *Scomberomorus concolor* (Croker 1937*a*); and Mexican scad, *Decapterus hypodus* (Croker 1937*c*). Although I could find no official record of the snapper catches reported by Mr. Wilson, this is not sufficient reason for rejecting his information.

The Estero Bay snapper has been deposited in the fish collection of the Natural History Museum of Los Angeles County (LACM 36009-1).

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SYMBIOTIC BURROW-OCCUPYING BEHAVIOR IN THE BAY GOBY, *LEPIDOGOBIUS LEPIDUS*

The symbiotic occupation of marine invertebrate burrows by members of the family Gobiidae has been observed in three species from California: the blind goby, *Typhlogobius californiensis;* the arrow goby, *Clevelandia ios;* and the longjaw mudsucker, *Gillichthys mirabilis,* (MacGinitie and MacGinitie 1949). In general these species utilize burrows as refuges from predators and dessication during periods of tidal exposure. Although MacDonald (1975) mentioned that bay gobies, *Lepidogobius lepidus,* might display this behavior, my report is the first qualitative record of symbiotic burrow-occupying behavior in this species. Little published information exists on this goby and authors have commented on its apparent rarity (Carrington 1954; Pearcy and Myers 1974).

MATERIALS AND METHODS

My study was conducted in Morro Bay, California (35° 21′ N, 120° 51′ W), a shallow estuarine system formed by the drainage of two small streams. At mean high water, the Bay covers about 810 ha (2,000 acres); at mean low water approximately 567 ha (1,400 acres) are exposed (Fierstine, Kline, and Garman 1973).

Bay gobies were collected in Morro Bay from an area primarily comprised of mudflats exposed during low tides of 0.0 height or less. This site is the intertidal area of Zone IV described by Fierstine, et al. (1973).

Benthic algae, mainly *Ulva* and *Enteromorpha* spp, and beds of eel-grass, *Zostera marina,* are common. The invertebrate fauna is highly diverse and the burrows of crustaceans, molluscs, and echiurans are numerous. Gobies were collected by hand or with the aid of quinaldine and dip nets in isolated mudflat tidepools. Burrow inhabitants were identified by excavating their burrows.

RESULTS

Eight specimens of *L. lepidus,* ranging in length from 56 to 78 mm (2.2 to 3.1 inches) standard length were taken from burrows during the period of December 1975 to May 1976. Three fish were removed from burrows of the blue mud shrimp, *Upogebia pugettensis* (Figure 1), two from the siphon holes of geoduck clams, *Panope generosa,* and three from burrows of the echiuroid worm, *Urechis caupo.* An additional 168 specimens of *L. lepidus* were removed from unidentified burrows in an area with dense populations of *Upogebia pugettensis* and *Urechis caupo.*

FIGURE 1. An anesthesized bay goby, *Lepidogobius lepidus,* emerging from a suspected *Upogebia pugettensis* burrow. *Photograph by author.*

DISCUSSION

My collections indicate that *L. lepidus* is one of the numerically dominant fish species in the lower intertidal zone of Morro Bay, although Fierstine et al. (1973) captured only one bay goby in 3 years of otter trawling, even though a large portion of their sampling was within 10 to 50 m (33 to 164 ft) of my collection

sites. In their study of larval fishes collected by plankton nets in Yaquina Bay, Oregon, Pearcy and Myers (1974) found the bay goby was one of the two numerically dominant species. However, W. Johnson (cf. Pearcy and Myers 1974) collected relatively few specimens in trawls made during a survey of benthic juvenile fishes conducted during the same time period. Extensive collecting efforts in Morro Bay have also indicated that seining is an inefficient method of sampling bay gobies in areas where burrows are available (Grossman, unpublished data). When faced with an approaching trawl, seine, or other disturbance, the bay goby probably retreats into the nearest hole, only to emerge when the danger is past. This behavior has been observed when fish in aquaria with artificial burrows were startled. Thus traditional collecting techniques (i.e. seines and trawls) may not adequately sample this species in areas where invertebrate burrows are present. Burrow occupation by bay gobies probably accounts for their rarity in other fish collections made south of San Francisco Bay (Fitch 1949; Carrington 1954; Allen 1976).

ACKNOWLEDGMENTS

I am deeply appreciative of the invaluable services rendered by H. L. Fierstine and Diana Crawford during the course of this investigation. I wish to thank the following people for their aid in the collection of specimens: Eric Castain, William Duckwall, Eric Hochberg, Elliot Menache, Linda Peets, Belinda Sampson, and Dennis Sheridan. E. G. Brothers, H. Fierstine, P. Moyle, and C. Swift reviewed the manuscript.

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FLOCK SIZE AND DENSITY OF COMMON MERGANSERS IN NORTHWESTERN CALIFORNIA

Between August 1972 and December 1973, a study was made to determine the seasonal variation in population density and flock size of Common Mergansers, *Mergus merganser,* in northwestern California. Brood size and spacing of common mergansers in this region were reported previously (Foreman 1976). The study area included about 92 km (57 miles) of the Klamath and 40 km (25

miles) of the Trinity rivers in Humboldt and Del Norte counties (Foreman 1976).

Data on the distribution of birds upstream from the estuary were gathered on 17 float-trip censuses and 13 roadside censuses. Float-trip censuses ranged from 11 km (7 miles) to 110 km (68 miles) and totaled 660 km (410 miles). Roadside censuses totaled 288 km (179 miles). Data on birds in the 1800-ha (4,400-acre) Klamath River estuary were gathered on nine roadside censuses.

In spring (March–May), birds formed pairs and small flocks (Figure 1) and spaced themselves evenly along the rivers; upstream density was highest during this season (Table 1). The estuarine population during spring was low due to the movement of birds upstream and northward to breed.

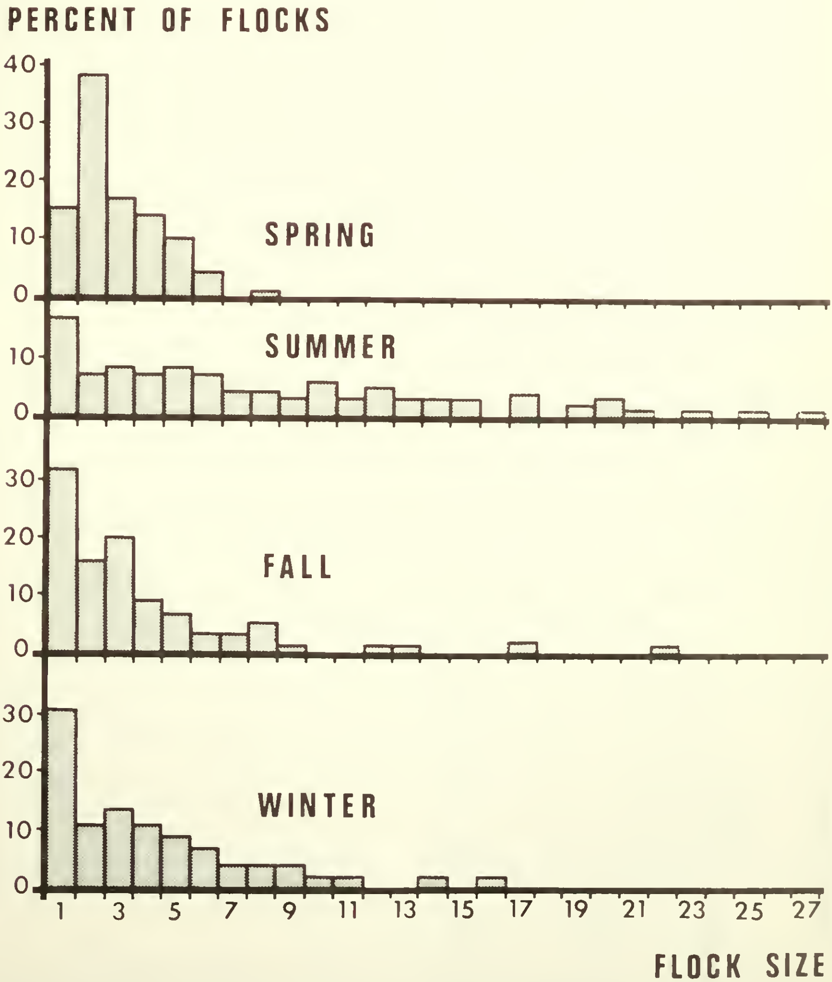

FIGURE 1. Percent frequency distribution of flock sizes of Common Mergansers observed in four seasons along the Klamath and Trinity rivers in northwestern California, 1972–73.

TABLE 1. Flock Size and Density of Common Mergansers Recorded on 39 Censuses of Klamath and Trinity Rivers in Northwestern California, 1972–73.

Season	*Number of censuses*	*Length (km)*	*Number of birds*	*Number of flocks*	*Birds per km*	*Flocks per km*	*Flock size (± S.D.)*	*Number adult males (%)*
Upstream Klamath and Trinity Rivers								
Spring	10	200.2	424	149	2.12	0.74	2.85 (± 1.49)	189 (45)
Summer	9	439.5	793	101	1.80	0.23	7.85 (± 6.33)	*
Fall	7	166.1	321	87	1.93	0.52	3.69 (± 3.82)	89 (28)
Winter	4	142.1	222	55	1.56	0.39	4.04 (± 3.43)	60 (27)
Klamath River Estuary								
Spring	3	16.8	27	5	1.64	0.30	5.40 (± 2.51)	19 (70)
Summer	3	16.8	9	3	0.54	0.18	3.00 (± 1.00)	*
Fall	1	5.6	50	2	8.93	0.36	25.00 (± 8.49)	45 (90)
Winter	2	11.2	53	4	4.73	0.36	13.25 (± 7.27)	38 (72)

* Males in eclipse plumage and not distinguishable from females.

Since most of the upstream flocks contained broods in the summer (June–August), flocks were relatively large. Only 29% (0.52 birds/km) of all birds in these flocks were adults or yearlings. Despite the addition of broods, the upstream density was lower in summer than in spring. This net decline was probably due to the departure of adult males and perhaps yearlings from the breeding grounds (Meigs and Rieck 1967, Erskine 1971). However, males and yearlings did not go to the estuarine area, as shown by the low summer density there.

In fall (September–November), upstream density rose slightly due to immigration of birds from the north or movement of broods downstream into the study area from the interior. The estuarine density increased in fall and consisted primarily of adult males (90%). Upstream flock sizes decreased as broods dispersed.

Upstream density was lowest in winter (December–February), while density in the Klamath River estuary remained relatively high. The flock size distribution remained about the same as during the fall.

Despite large seasonal variation in fish abundance and stream flow, merganser density in the upstream areas did not vary greatly through the year. However, dispersion of birds along the rivers varied greatly due to pairing, brooding and wintering activities.

ACKNOWLEDGMENT

I thank Stanley W. Harris for his guidance during the study.

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AN EXTENSION OF THE KNOWN RANGE OF *NEOMYSIS MERCEDIS*, THE OPOSSUM SHRIMP

The opossum shrimp is an extremely important fish food in the Sacramento-San Joaquin Estuary. This Estuary and Lake Merced were reported to be the southernmost locations from which it had been collected (Holmquist 1973). Temperatures farther south were thought to exceed its upper lethal limit of approximately 25.4 C (77.8 F) (Hair 1971, Heubach 1972). However, Needham (1940) found *N. mercedis* in Waddell Creek, 23 km (39 miles) south of Lake Merced. During August and October 1977 we sampled the mouths of 18 small coastal streams from 50 km (30 miles) south of San Francisco to Ventura, California to determine how far south this species actually ranged (Figure 1).

METHODS

Sampling locations included stream mouths barred from the ocean by sand and nearby ponds and lagoons. Samples were collected at the northern six stations with a 505-μm (0.02-inch) mesh plankton net, 1.48 m (58 inches) long

and 0.065 m^2 (100 $inch^2$) in mouth area. Depending on the water depth, it was pulled behind an inflatable raft or aluminum boat or by a wading person. At the southern stations a 1.52-by 1.52-m (5-by 50-ft) seine with 0.64-cm (25-inch) mesh was used. Water samples were taken for electrical conductivity measurements. These measurements were converted to approximate salinities in parts per thousand.

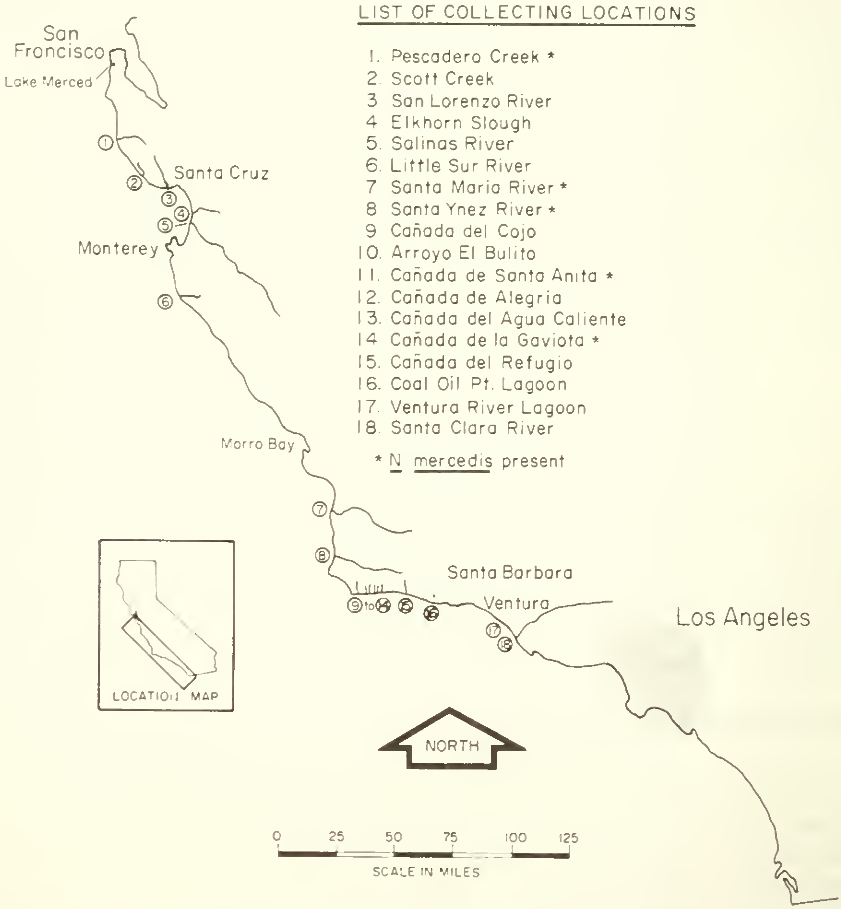

FIGURE 1. *Neomysis mercedis* sampling locations

RESULTS AND DISCUSSION

N. mercedis was taken in abundance (often more than 50 per tow) at 6 of the 18 locations sampled (Figure 1, Table 1). A new southern limit for the species was established at Gaviota, 19 km (12 miles) below Pt. Conception and approximately 280 coastal miles from Lake Merced.

Environmental conditions where *N. mercedis* was taken varied widely (Table 1). *N. mercedis* was found from freshwater to highly saline water (at least

27.6‰ and possibly 32.3‰ salinity), in clear water where the bottom was visible at 1 m (3.3 ft), to very turbid water. It was found in streams with closed mouths, in a freshwater pond temporarily separated from the sea, and in a lagoon open to the sea. We could not readily differentiate habitats where it was present from those where it was absent. Hence, we have not drawn any conclusions as to the habitats where this species will or will not be found, although all locations where it was found had some connection with the ocean during part of the year.

TABLE 1. Salinities where *N. mercedis* was found.

Location	*Salinity (‰)*
Mouth of Pescadero Creek	13.1
Mouth of Scott Creek	18.5
Santa Maria River, pond * (surface)	0.5
(bottom)	2.2
Santa Maria River, lagoon * (surface)	1.6
(bottom)	32.3
Mouth of Santa Ynez River	7.8
Mouth of Cañada de Santa Anita	27.6
Mouth of Cañada de la Gaviota	16.4

* Layer in which the mysids occurred could not be determined.

Except for the Santa Maria River all locations were sampled in October when temperatures were below the annual maxima, so we do not know how close temperatures might have approached the upper lethal level. The Santa Maria River lagoon was sampled in August when temperature was probably close to the maximum. Temperature there was stratified, 25 C (77 F) at the surface and 16.6 C (61.9 F) at the bottom. Because the water was so shallow 60 cm (24 inches) it was not possible to determine in which layer the mysids were.

Although our sampling establishes Gaviota as the southernmost location where *N. mercedis* has been found, this species may occur in unsampled locations father south. It also may occur in locations in which we sampled but did not find it.

N. mercedis has been found in the ocean only near river mouths. Although it is abundant in California's Sacramento-San Joaquin Estuary (Heubach 1969) and extends as far downstream there as San Francisco Bay (Tattersall 1932), it has not been collected in plankton tows in the ocean off of San Francisco (Robert Tasto Calif. Fish and Game, pers. commun.). The highest confirmed salinity in which it has been found was 30‰ in Echo Bay, Sucia Island, Washington (Holmquist 1973). In the small California coastal streams where we found *N. mercedis,* high winter flows breach the sand bars and presumably sweep the mysids into the ocean where salinity normally is about 34‰. It is not known if they survive the salinity changes they experience when this happens. If they do, they may re-enter stream mouths when the high flows subside, and this may be the mechanism that has spread them along the coast.

ACKNOWLEDGMENTS

We would like to thank Shoken Sasaki, Department of Fish and Game and Gary Curtis, now with the National Marine Fisheries Service, for their participation in this study.

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BOOK REVIEWS

Owls by Day and Night

by Hamilton A. Tyler and Don Phillips; Naturegraph Publishers, Inc., Happy Camp, California 96039, 1978; 208 pages; illustrated. $6.95 paper; $10.95 cloth.

It seems owls eventually arouse the interest of any serious birder, but because of the nocturnal nature of owls, few birders actively seek these creatures. "Owls by Day and Night" is designed to assist the amateur birder in finding and identifying owls in the field. Hamilton Tyler uses the first part of this book to not only develop the idea that the owl and its historical relationship with man clearly differentiates it from other birds, but also to distinguish one owl from the next. To aid in this task, a series of tables are used to facilitate the physical and vocal identification of the 18 species of North American owls, as well as their distribution.

The usual species description and life history reports further differentiate one species from another. Though many of the species accounts relate directly to observations made in California, they are quite complete without going to the extent of Bent's "Life History" series. Tyler's obvious love for owls is evident, as is his concern for their conservation; the final chapter discusses mans' present effects on specific habitat types necessary for sustaining certain species of owls.

The paintings by Don Phillips are beautiful, but may be too perfect to be useful to the beginner. The beginner may be too involved in the nondistinguishing features vividly portrayed in some of the paintings to see the distinguishing features. Usually the more experienced birder will know what characteristics to look for and thus not rely on the pictures. I think Phillips' excellent black and white drawings and Tyler's identification tables categorizing owl characteristics are far better tools for field identification.

"Owls by Day and Night" ends with two fascinating appendices: The first lists alternate common names, useful in relating to the proper species in other literature; the second explains the derivation of the scientific names for each species, providing insight into the relationship between species and to the characteristics the original investigators noticed when describing the species in question.—*Gordon I. Gould, Jr.*

A Master's Guide to Building a Bamboo Fly Rod

by Everett Garrison with Hoagy B. Carmichael; Martha's Glen Publishing Co., N.Y., 1977; 296 p.; illustrated. $20.00.

This book provides comprehensive coverage of the art of building hand made six-strip bamboo fly rods. It describes in great detail the rod building techniques of the late Everett Garrison, one of the finest custom rod makers. Garrison fly rods are among the highest priced of the top-quality rods and are in great demand by fly fishermen and collectors.

While modern builders of bamboo rods generally use power saws and strip cutting machines, Garrison preferred to split and bevel the cane strips entirely by hand. This method of construction is well suited to the beginning rod maker since rod blanks can be made without a big investment in special machinery. Much of work can be done with ordinary hand tools and equipment that can be made in the home workshop. However, the steel planing form that Garrison designed requires accurate machining and is best made in a machine shop. A small screw-cutting lathe is very helpful in fitting ferrules and shaping rod grips but the beginning rod maker can get along without one if he doesn't care to make his own ferrules and metal reel seats. Suppliers of materials, tools, and fittings are given.

Garrison held a degree in Structural Engineering and used his engineering background to develop the tapering formulas for his fly rods. A chapter is devoted to the steps involved in calculating rod tapers. The beginning rod maker can use the formulas to design his own fly rod or he can use one of Garrison's popular tapers which are also included.

The authors reveal many special techniques and details of equipment that could rightly be called trade secrets. The design of the adjustable planing form, rod tapers, "heat treatment" of the cane strips, apparatus for varnishing rods, and repair of broken rods are some of the things that many rod makers would be unwilling to make public.

This book is extremely well illustrated, with over 370 excellent photographs and many technical drawings. I highly recommend it to anyone interested in building or repairing bamboo fishing rods.—*William F. Van Woert*

Larvae of the North American Caddisfly Genera (Trichoptera)

by Glenn B. Wiggins; University of Toronto Press, Toronto, Ontario Canada, M5S 1A6; 1977; 401 pages; illustrated. $25.00.

This volume is destined to become one of the classics of modern entomology. Dr. Wiggins has put an impressive amount of information regarding larval Trichoptera into this remarkable volume.

The scientific illustrations, beautifully drawn by Mr. Anker Odum, are the best that have appeared in any comparable volume in recent years. They convey an impressive amount of morphological information on each of 142 genera, comprising 18 families. The authors' stated objective is to show that learning is easier and more exciting when utilizing extensively illustrated keys. Dr. Wiggins has succeeded remarkably in reaching his stated objective.

Some of the topics covered in the early chapters of the book include: classification and phylogeny, ancestral habitat, habitat diversity, respiration, feeding, case making, life cycles, morphology, and collection and preservation techniques.

The volume is remarkably free of typographical errors. The bibliography, containing almost 300 literature citations, is probably the most extensive ever assembled on larval Trichoptera.

Serious students of benthic biology and aquatic entomology will find this book an invaluable addition to their reference library.—*Michael L. Johnson*

Terrestrial Vegetation of California

edited by Michael G. Barbour and Jack Major; Wiley-Interscience Publication, New York, 1977; 1,002 p.; illustrated. $47.50.

This volume is an outstanding work on California's rich and varied flora. The editors had two objectives in compiling this book. The first was to summarize and review the extensive but fragmented literature on California flora. The second objective in the words of the editors "was to build upon that review, to derive conclusions or hypothesis, to formulate models, to reconstruct the past or predict the future, and to highlight the areas that should receive further study." To this end the editors enlisted the assistance of almost forty authorities in the field of botany or plant ecology.

The book is divided into seven sections. The first section is a general overview with chapters on climate, history of California vegetation, status of vegetative mapping in California, research natural areas, and several similar subjects. The remaining six sections deal with major floristic provinces; California, Sierran, Pacific Northwest, Great Basin, Hot Desert, and Southern California Islands. Within each section, chapters cover dominant vegetative associations such as oak woodland chapparel, mixed evergreen forest, etc. Detailed diagrams and tables are presented throughout the book with extensive literature citations at the end of each chapter. A large colored map of the State showing the distribution of 54 vegetative types is included with the book.

From this description it should be apparent that this book is a scientific, technical work and will be most useful to ecologists, botanists, foresters, range managers, game managers, and others who need a good reference on plant ecology of California. However, I think that anyone with a basic knowledge of and an interest in California natural history will be able to read this volume and find it instructive and enjoyable. I should also point out that sections or chapters can be read independently so that a person interested in a particular area or vegetative association will not have to read the entire book, although it would be well worth the effort.

With a price tag of $47.50, many people may be reluctant to purchase this book. However, those interested in this field will find the book well worth the price and a welcome addition to their library.—*John Geibel*

Coastal Resources Management

by Robert B. Ditton, John L. Seymour, and Gerald C. Swanson; Lexington Books, D.C. Heath and Company, Lexington, Massachusetts; 1977; 196 p.; $16.50.

The authors state that the purpose of the book is to explore two basic themes: "(1) the nature and uses of coastal resources and (2) the allocation, or management of these scarce resources." They do explore these themes, but do so in what appears to be a superficial manner. The book is mainly concerned with overall strategies of the 30 state coastal zone, with very little that is included dealing specifically with the West Coast. The exception to this is Chapter 9, which provides an in-depth case study of the San Francisco Bay Conservation and Development Commission. The California Coastal Zone Commission rates only two lines on page 119 and the volume contains absolutely no mention of anadromous fishery resources within the coastal zone.

Some of the topics dealing with coastal resource management covered in this volume include: the issues of coastal use from the perspectives of preservation and development, historical aspects,

economic aspects, legal aspects, regulation and the Coastal Zone Management Act, interdisciplinary tools for resolving coastal conflicts, and overall management strategies.

It appears that this volume is intended more as a textbook and a general reference for planners, administrators, and other policy makers, providing background for understanding coastal zone management on a national scale. It possesses only limited value for those conservationists engaged in the day-to-day struggle to preserve California's rapidly dwindling coastal resources, especially since the volume appears to be significantly overpriced.—*Michael L. Johnson*

Indian Fishing

By Hilary Stewart; University of Washington Press, Seattle and London; 1977; 181p; illustrated; $17.95.

This fine volume will appeal to a wide range of specialties, including fishery biologists, anthropologists, sociologists, and outdoor educators. The author has authored many publications dealing with the archeology of the northwest coast area. Her specialty has been ethnobotany and the technology of native plant uses. In recent years, her interests have broadened to include the fish technology of the coastal peoples. In addition, she has been actively involved in outdoor education and survival in the wilderness.

Some of the many topics covered include: hooks, lines, sinkers, spears, harpoons, nets, traps, weirs, and methods of cooking and preserving fish. Fish taken by these early fishing methods included: shellfish, salmon, rockfish, herring, eulachon, sturgeon, halibut, and others. The book concentrates geographically on an area along the coast from Washington to Alaska.

The author's drawings are superb, showing great concern for detail and process. However, the real value of these drawings is that they show *how things work*. It is this that sets this volume above all other comparable books.

This book is not an account of fishing technology of the Pacific Northwest Indians, rather, it is an account of how fish and fishing were interwoven into the total life style of these early native peoples. It must be recognized that this is not a scientific book written by a scientist for other scientists. Rather, it is a book that many scientists and non-scientists will find highly informative, and perhaps this is where its true value lies.—*Michael L. Johnson*

The Breakdown and Restoration of Ecosystems

Edited by M. W. Holdgate and M. J. Woodman; Plenum Press, New York; 1978; $30.00.

This volume contains the Proceedings of the Conference on the Rehabilitation of Severely Damaged Land and Freshwater Ecosystems in Temperate Zones held in Reykjavik, Iceland, July 4–16, 1976, sponsored by the NATO Special Panel on Ecology. The book is divided into four major sections: basic ecological principles, the degradation of land and freshwater ecosystems in temperate lands, the restoration of degraded ecosystems, and final discussion. A total of 24 major papers is presented. As with most symposia volumes, the quality of the papers are somewhat uneven. However, for the most part, they are of high quality and extremely interesting.

Some excellent papers on ecosystem computer modeling are presented. Problems of erosion are discussed in several papers, including one paper entitled "Fire and Degradation of Ecosystems". Wildlife biologists will find Lee Talbot's paper on "Predators in Ecosystem Management" extremely interesting and perhaps somewhat disturbing. Three papers dealing with restoration of damaged lake ecosystems will be of value to limnologists.

Probably the most important sub-section of the book is entitled "Patterns of Land Use". This sub-section includes three papers which deal with utilization of ecological principles in the planning process. The last chapter suggests that the professional ecologist can contribute both to the protection and rehabilitation of ecosystems by participating in five main areas: conducting surveys, evaluations, statement of issues for the public, design and supervision of environmental protection and rehabilitation schemes, and general monitoring of ecosystems. A strong plea is made for the environmental scientist to communicate with non-scientists, especially in the area of policy definition. Environmental scientists must realize that non-scientists do not read the scientific literature. One paper cites a 400 year old quote by Sir Francis Bacon: "Nature cannot be commanded except by being obeyed".

This volume deserves to be read in detail by all administrators and scientists who deal with environmental problems in "real world" situations. It is an excellent book.—*Michael L. Johnson*

Desertification: Environmental Degradation in and around Arid Lands

Edited by Michael H. Glantz: Westview Press, Boulder, CO; 1977; 353p; $20.00.

Desertification is defined as "the creation of desert-like conditions in arid or semiarid regions either

by changes in climate patterns or by human mismanagement, or both". Desertification has become recognized in recent years as a major world-wide problem occurring in Africa, South America, Asia, and North America. The essence of the problem is summarized in the foreword by Dr. Viktor A. Kovda of the U.S.S.R.

> "On vast areas of the land droughts occur ever more often. Resources of the fresh surface and ground waters decrease noticeably. The erroneous methods of the utilization of natural resources by man—complete clearing of the forests and shrubs on the vast areas, overgrazing and destruction of the grass sod by animals, ploughing of the slopes, monocultural farming practices and regular burning of the vegetation—have aggravated the general unfavorable tendencies of land aridization in our time. The original fixed sands of savannas, steppes, and semideserts began to shift and creep over the fields, roads, and wells. Dust storms destroy the soils of the cultivated fields and ruin the crops. Water erosion destroys the arable humus layer of the soil and its fertility. The albedo of the stripped soil increases multifold. The water content in the soil goes down, whereas the surface evaporation goes up. The processes of the accumulation of toxic salts in the soils and natural waters gain speed. The vegetation cover deteriorates. The . . . landscapes change . . ."

There have been seven major international conferences dealing with this problem since 1970. While some solutions have been proposed, political and cultural obstacles prevent international programs from becoming effective. The contributors to this volume have done an excellent job of examining and evaluating the multidisciplinary problems relating to the cause and effects of desertification. I highly recommend this volume for all scientists and administrators who have an interest in the causes, effects, and solutions to this critical international problem.—*Michael L. Johnson*

Water Chlorination: Environmental Impact and Health Effects, Volume 1

Edited by Robert L. Jolley; Ann Arbor Science Publishers, Ann Arbor, 1978; 439p; $22.00.

Water Chlorination: Environmental Impact and Health Effects, Volume 2

Edited by Robert L. Jolley, Hend Gorchev, and D. Heyword Hamilton, Jr.; Ann Arbor Science Publishers, Ann Arbor, Michigan; 1978; 910p; $30.00.

These two volumes contain the papers presented at the 1975 (Volume 1) and the 1977 (Volume 2) conferences on the environmental impact and health effects of water chlorination. To realize the magnitude of the problem, it must be realized that over 420,000 tons of chlorine are used annually for "sanitary purposes" in the U.S. These uses include potable and wastewater treatment, swimming pools, household uses, etc.

Limited research was conducted on chlorination from 1950 to 1970, however, research on the many aspects of chlorination increased rapidly in the 1970's. This activity concentrated on four major areas: toxicity of active chlorine to aquatic life, formation of chlorinated organic compounds in the chlorination of wastewater effluents, the persistence of chlorinated organic compounds in the environment and their accumulation in the food chain, and the formation of haloforms in the chlorination of drinking water supplies. These books summarize the results of past and ongoing research into these topics and point the way for future research goals.

Aquatic and marine scientists, especially those working with water quality problems relating to chlorine residues, would be well advised to have these two volumes available in their reference library.—*Michael L. Johnson*

The Little Known Pika

By Robert T. Orr; McMillan Publishing Co., Inc., New York; 1977; 144pp; illustrated; $7.95.

Dr. Orr has provided us with an excellent narrative description of the fourteen known species of pikas and their habitats. The pikas are restricted to high mountain rockslide areas which may explain why so little is known about these interesting little lagomorphs. The author has traveled extensively in Asia as well as North America and observed many of the known species in their native habitat. Twelve species are native to Asia with the remaining two species occurring in North America. Dr. Orr describes the details of the pika's daily life with many side notes on the natural history of the various habitats. The book is divided into spring, summer, autumn, and winter plus sections on taxonomy and general environments.

The author has provided an excellent bibliography and the volume is well indexed. The book is free of typographical errors and the quality of photographs is excellent. The book should not be regarded as a scientific treatise, rather as a highly informative natural history of one of the lesser known mammals. Many biologists will find this reasonably priced volume a welcome addition to their libraries.—*M. L. Johnson*

Mexican Wilderness & Wildlife

By Ben Tinker; University of Texas Press, Austin, Texas; 1978; 131pp; illustrated; $9.95.

The author has spent a major portion of his life exploring and working in the vast Mexican wilderness of the Sierra Madre and the deserts of Sonora and Baja. Although an American citizen, he was appointed the first Federal Game Guardian for this immense area by the Mexican Government in 1923. Following completion of the appointment in 1926, he returned to ranching in the southeast Sonora area where he continued his studies of indigenous wildlife.

Mr. Tinker presents life history sketches of seven big game animals: desert bighorn, pronghorn, mule deer, whitetail deer, collared peccary, grizzly bear, and the wild turkey. Also included are life history notes on five major predators: mountain lion, wolf, coyote, jaguar, and the bobcat. A description of the terrain and flora of the four major life zones inhabited by these animals is included along with a section on desert water and arid environment adaptations. He also reports on trout fishing in the Sierra Madre along with a brief, interesting discussion of wildlife conservation in Mexico.

The foreword, written by Dr. A. Starker Leopold in 1971, states: "In the last two or three years Mr. Tinker has demonstrated to my complete satisfaction that his knowledge of the wildlife of Northern Mexico is far superior to my own. His personal knowledge of wildlife of Mexico richly deserves publication and general dissemination." The many widllife illustrations by Doris L. Tischler are of a superb, haunting quality which greatly enhance the volume. The book is remarkably free of typographical errors.

This fascinating volume will be a valuable resource for sportsmen, fish and wildlife biologists, students, conservationists, naturalists, and all others interested in the ecology of this fascinating wilderness of Northern Mexico.—*Michael L. Johnson*

The Living World of the Reef

By Hillary Hauser and Bob Evans. Walker Publishing Company, 1978; 96p., illustrated, $6.95.

For the past few years, we have seen a number of books, primarily coffee table picture books, dealing with tropical coral reefs and their ecology. I have long felt that there was a definite need for a similar type of book on temperate reef communities not only of the Pacific coast but of the Atlantic coast as well. *The Living World of the Reef* is an attempt in this direction. Unfortunately, it falls short in several areas.

In the first place, it deals primarily with the offshore reef communities around the Channel Islands of southern California which are certainly not representative Pacific coast temperate reefs. In the second place, the narrative descriptions fall short in many cases in describing the intricate community structure. Finally, the book contains many errors in terms of life history, identification, etc. For example, in discussing the marine mammals and the impact of the intensive hunting of these animals in the 1880's, the authors completely left out the sea otter and the role it played in this tragic history. In another case, in discussing cabezon, *Scorpaenichthys marmoratus,* spawning habits, they neglect to point out that the eggs are guarded by the male. Finally, they describe the mola, *Mola mola,* as a poor swimmer and its wanderings as aimless. To the contrary, anyone who has observed these unique fish or tried to chase one can attest to their excellent swimming abilities and, based on many years of observation, it is evident that there is a definite pattern to the movements of the molas, at least along the California coast. Finally, the sea cucumber identified as *Parastichopus parvimensis* on page 27, is actually a *Parastichopus californicus.*

On the bright side, the photographs are outstanding and they alone are worth the price of the book. Because of the photographs, the book should prove to be a pleasing introduction to southern California reef animals for most sport divers and some biologists.—*Daniel W. Gotshall*

Why Big Fierce Animals are Rare

By Paul Colinvaux; Princeton University Press, Princeton, NY; 1978; 256pp; $9.50.

This superb little volume turned out to be one of the most pleasant surprises of the year. The author has an easy-going narrative style that takes complex ecological principles and explains them in easy to understand language for the reader. This is not a book you teach from, rather it is a book that is meant to be read. The author's essays are thought-provoking and penetrating, covering a multitude of issues and topics such as territoriality, predation, energy flow, natural selection, population dynamics, succession, and human ecology. This book will appeal to the hiker and amateur naturalist as well as the professional ecologist. It deserves a place on the bookshelf of all biologists, no matter

what their specialty or interest. Dr. Colinvaux is Professor of Zoology at the Ohio State University and is the author of *Introduction to Ecology* (Wilde).

For those of you who wish to know "why big fierce animals are rare", I suggest you read this excellent volume. It is a real treat.—*Michael L. Johnson*

The California Quail

By A. Starker Leopold; University of California Press, Berkeley, CA; 1978; 281pp; illustrated; $14.95.

Professional wildlife biologists, managers, academic instructors, and students have long awaited this landmark volume. Dr. Leopold states in the preface that his intent was "to assemble in one set of covers all that is known to date about the ecology, natural history, and management of the species." I believe that he has succeeded admirably in accomplishing his stated goals.

The volume is divided into three main parts plus three appendices. Part I deals with the quail and its history. Part II concentrates on natural history and covers social behavior, covey break-up, nesting, growth and development, sex and age ratios, effects of rainfall on reproductive success and quail mortality. Part III discusses cover, food, water, hunting, and backyard quail management.

The three appendices are well worth noting: *Quail in in Aboriginal California* by Karen M. Nissen, *Foods of the California Quail* by Bruce Browning, and *Effects of Differing Rainfall on Breeding of California Quail* by Michael J. Erwin. These three appendices greatly enhance the value of the book for the reader.

Dr. Leopold has included a comprehensive bibliography and a useful index. The quality of the drawings by Gene Christman are of excellent quality and greatly enhance the book. The photographs are of high quality and the book is free of noticeable typographical errors. It deserves a special place in the library of all professional wildlifers who may be involved with this superb game bird. Many sportsmen will find it useful and informative.

The author states, in Chapter Three, "If this volume on the California quail is to serve any real purpose, it will be through bringing to the attention of landowners and operators—public as well as private—the rudiments of management of the landscape necessary to favor the welfare of the species. The only approach to quail management that offers assurance of success is habitat restoration and maintenance by those individuals and agencies that manage the land."—*Michael L. Johnson*

Pacific Salmon, Management for People

Edited by Derek V. Ellis; Western Geographical Series, Vol. 13; University of Victoria, Victoria, B.C.; 1977 320pp; illustrated. $4.00

This reasonably priced paperback volume is the 13th in the *Western Geographic Series*. Although the emphasis of the book is on British Columbia, the editor has taken pains to discuss the entire salmon fishery from California to Alaska.

The introductory chapter, written by James A. Crutchfield, discusses the economics of the salmon fisheries. In summary Dr. Crutchfield states "It may well be that the corner has been turned with respect to preservation and even some rebuilding of the salmon resources of the Northwest. What remains unclear is whether Canadian and American governments will determine to face, resolutely and patiently, the difficulties involved in moving toward a management regime that will reasonably approximate optimal utilization of the stocks. Fisheries science has provided far more tools than fishery management has been able to use, given the political timidity and the confusion over objectives that have characterized salmon management throughout this century".

Other topics include recreational fisheries, limited entry in Alaska, ethology, enhancement technology, and a thoughtful discussion of salmon management objectives. This volume contains much valuable information, especially for those biologists who do not work day-after-day with these resources, but only occasionally have need to become familiar with the current literature. The chapters on Ethology, management objectives, and practical management are especially informative.

College educators should include this book as required reading for all students studying resource management. In addition, it should be read by all administrators who have programs dealing with these valuable and unique fish. The price and quality of this book almost mandate its inclusion in the personal libraries of all fishery research and management biologists.—*Michael L. Johnson*

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